INSTITUTE *of* STATISTICS
Oxford

Bulletin Vol. 21 *August 1959* *No. 3*

INNOVATION AND AUTOMATION:

A DISCUSSION BASED ON CASE STUDIES

By

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Acknowledgment

The present study, which arose out of a suggestion by the Department of Scientific and Industrial Research following the proposals outlined in their pamphlet on '*Automation*', was completed in 1958. The Institute is grateful to the D.S.I.R. for having made the study possible by a generous grant to the University.

We owe moreover a very real debt to the many managers, engineers, accountants, and work study experts in the firms we visited, who not only put up with our questions with exemplary patience but were quite ready to impart their understanding and insight into the problems we discussed. We have drawn very freely on their data, their special studies, and their opinions; but the shortcomings of the work must obviously be considered our own.

We have further to thank many other people and organisations, including the Institution of Production Engineers, the Institute of Cost and Works Accountants, the Production Engineering Research Association, *Metalworking Production*, and several machine-tool manufacturers and their agents, from whom we also received a great deal of patient help and guidance.

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INTRODUCTION

Industrial innovation is hardly a new thing, although some recent instances have been distinguished by a new name. The various distinctions made in current literature between automation and mechanisation are essentially technological; but they are given an emotive flavour by the suggestion that they portend a speed of industrial advance of which the social consequences may prove uncontrollable. In this Luddite setting the application of electronics, and the advances in the older technique of transfer machining, are alike taken to characterize a further industrial revolution, led by a stage army of machines.[1] The assumptions of the literature—however much they may be hedged with disclaimers—are two; first, that there will be a universal progress from the present level of mechanisation to a virtually ' complete ' mechanisation; and second, that this progress will be rapid. The less either of these conditions is satisfied, the weaker becomes the distinction between automation and previous technological advances. In themselves, the features which are supposed to distinguish the automation age—a switch from ' motor ' to perceptual elements in skill,[2] an increased ratio of managers and technicians, and a corresponding recasting of education—are hardly novel: they were features of technological advance in the nineteenth century. The purpose of most technological development is, in some sense, to ' save labour ': this goes, of course, for the ' brain-saving ' of the newer electronic control mechanisms as well as for the ' brawn-saving ' of the older machines. But the effects of new techniques on employment are inevitably complex and indirect; as economists have often pointed out, these effects can spread from industry to industry, region to region, country to country, and then return again. Even if labour is really saved, it may only be saved for other jobs, which may be called into being by demands which consumers can still make effective. What slack there is may either be enjoyed as leisure or endured as unemployment; it is still only in a science-fiction world that machines, unattended and unmaintained, make other machines, install them where they are needed, replace them when worn out, decide when they are obsolete, and invent their successors.

The factors at present impeding progress to ' complete ' mechanisation are, of course, economic as well as technological: for instance, where firms have too little command of capital to re-equip completely with the most advanced machines—or where their reserves are too small to justify the risk of large-scale pioneering. Even a powerful firm, in a trade where there is no guarantee of long runs of similar production, may hesitate to install machinery which cannot be adapted to changes in the level or composition of demand. Admittedly, sooner or later manufacturing industries could no doubt be re-equipped with tape-controlled groups of machine tools capable of turning out very varied products in as short runs as necessary; but such extensive re-equipment would not be possible without very great changes in economic organisation—to say nothing of the development of programming techniques. In the meantime (except for the office work of a few large firms[1]), it is mainly certain branches of processing industries—oil-refining, chemicals, food—where there are steady demands for uniform products, which exemplify anything like complete mechanisation. But these are industries in which mechanisation can, from an engineering standpoint, often be straightforward in so far as some of the more difficult mechanical problems do not arise. For example, whereas in metal-working industries such operations as accurate positioning and intricate machining are difficult to make fully automatic, these operations are virtually absent in processing industries; and the analogue to what may be, in engineering, a series of diverse and complicated assembly operations is, in—say—food preparation, a set of comparatively homogeneous and simple mixing operations. Even in processing industries, however, mechanisation has not been brought about overnight, but as the culmination of developments which have been proceeding steadily for many years.

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[1] LEO (London), the Ford engine plant (Detroit), and the Russian piston factory (?) recur regularly in automation literature.

[2] *Cf.* Department of Scientific and Industrial Research, *Automation*, H.M.S.O., 1956, p. 73.

Typically, indeed, mechanisation proceeds piecemeal and remains patchy, if only because capital limitation ensures in most cases that it is based upon already existing plant. Even when a brand-new factory is set up, or existing capacity is greatly extended, or a whole department is re-equipped, firms will not always be able to commit themselves to the ' full automation ' of the visionaries, since some processes may be technically far more difficult to mechanise than others or, while technically simple, very expensive to install. Attempts have been made, understandably enough, to establish some sort of hierarchy of mechanisation: for example, one American study[2] specified seventeen ' levels ' ranging from ' hand operation ' at the bottom, through such stages as ' fixed-cycle power tools ', ' recording performance ', and ' identifying and selecting appropriate action ', up to ' anticipating required performance and adjusting accordingly ' at the top. The writer of the study took a number of processes in different industries and constructed a ' mechanisation profile ' for each, classifying every operation in the process by where it came in his hierarchy. In none of the cases recorded did even single operations reach very advanced levels, while in all there was some reliance on hand work.

Such a hierarchy tends to give an unduly deprecatory impression of achievement, in so far as it suggests that the highest level is necessarily the one towards which each part of the process ought to advance. The higher levels, with their prediction or their closed-circuit ' feed-back ' (or ' feed-forward ' for that matter), are useful only where conditions vary. Thus, if the quality of the final output is materially impaired by variations (for example, in external circumstances such as the weather, in the character of the raw

[1] Without wishing to imply an arbitrary distinction between ' productive ' and ' non-productive ' processes, we shall exclude office mechanisation from the scope of this report.

[2] James R. Bright, ' How to Evaluate Automation ', *Harvard Business Review*, July-August, 1955.

material, or in the accuracy of working in the earlier stages of the process itself), it is obviously desirable that the effect of these variations should be automatically offset. But if the process runs smoothly and reliably and deals with a uniform input, none of these more elaborate methods of control will be necessary. Many very simple processes can take widely varying material without the need of any adjustment—just as a funnel collects water from a wide area but confines its output to a small one, and many Procrustean manufacturing processes deal no less summarily and effectively with the wayward variations of their input. Indeed, a simple mechanical method, low on this technological hierarchy, might sometimes usefully replace a much more elaborate system: it may constitute an advance to step *down* the hierarchy. To take an everyday example, the substitution of the long-playing gramophone record for a set of short-playing records and an automatic record-changer is surely an advance, although the long-playing record is simpler. Admittedly, an apparent reversion to simplicity may merely mean that the complications have, so to speak, been pushed further back in the manufacture of the device; but this is not necessarily so. One of the possible sequences in industrial development may run as follows: first, machines are brought in to do simple jobs hitherto done by men; next, complicated machines take over the more difficult jobs still done by men; and finally, the machines may be simplified (perhaps with some redesign of the product) to do substantially the same jobs more easily and more cheaply. It is not suggested that this sequence exemplifies a law of technological advance; but its very possibility is enough to qualify the more common assumption of a law of increasing complexity.

Uneven development within or between productive processes has always been characteristic of mechanisation, as is amply testified by the economic history of the past two hundred years: obviously, new machines are introduced for the operations which seem to offer the greatest scope for their use, leaving ' pockets ' of comparatively primitive operating methods at various stages. In many cases, technical devices may be available to eliminate these pockets; but it may simply not pay to install them: ' we should not assume that mechanical achievement implies economic excellence. The point of diminishing returns is just as true in mechanisation as in anything else.'[1] It might well be decided to retain vestigial pockets, because to eliminate them would represent only a marginal gain in the short run which would be negatived in the longer run because the whole process would become less adaptable to economic changes—*e.g.* in demand or in relative costs; or their elimination might not promise even a short-run gain because it would make the process too inflexible mechanically. There are many ' philosophies of production,' and the philosophy of the single line—which leads so easily to the philosophy of the ' fully automatic ' line—has not by any means won the day, nor, in many cases, is there any reason why it should. For in a fully integrated automatic production line, the rate of flow is limited to that of the slowest machine or machine-group (the flow may, in fact, dry up if one of them stops) ; and this will mean that the faster (or more reliable) machines will be underutilised. It may still pay to install them; but it might pay even better to be able to use them nearer their capacity. The question of utilisation is one which may very well worry management: no one likes to see expensive machinery lying idle. For example, a particular machine may work fast enough to serve two lines, and if so there is no point in placing it in an integrated line: it may be better to set it apart where it can serve its two purposes, even though this isolation may involve extra (and not necessarily mechanical) handling of components. Thus the introduction of a machine of outstanding performance may, for the sake of retaining flexibility, actively delay the complete elimination of comparatively primitive types of operation. The need to retain flexibility in particular processes is, in fact, an important reason for the prevalence of piecemeal as against wholesale innovation: it tends to induce firms to parcel out their capital allocations for new plant between many processes in a number of departments rather than to re-equip a whole section completely. In other words, the natural reluctance to putting all one's eggs into one basket may be reinforced by the fear that the basket may prove too unwieldy for its purpose.

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[1] James R. Bright, *op. cit.*

The need for keeping flexibility is, in essence, the need of remaining adaptable to changes in demand. (The assurance of demand which springs from large markets is the currently quoted justification of the superior readiness of Americans to re-equip factories with specialised machinery.) Certainly some sort of assessment of future demand for a firm's dexisting proucts, or for new products which it might make, or in some cases both, are naturally implicit in every investment decision, although such forecasts may not be made very formally or carefully. After an agreement, tacit or otherwise, has been reached about prospective demand, any decision between alternative investments will rest—in theory at least—on considerations of cost. Not only may estimates of future demand obviously be liable to wide error margins, but cost comparisons—particularly for untried machines and processes, and most of all when new products are being planned—are necessarily somewhat speculative:

> 'Many firms that have introduced automatic techniques will freely admit that they began with much faith in them, but with little certain knowledge as to their profitability. Decisions had to rest largely on intuition so long as the relative costs of automatic and traditional machines were not properly known. Thus, progress . . . will depend on the willingness of firms to take the first imaginative steps, and that depends in turn on psychological factors, like the urge to be technically up to date and an optimistic assessment of future markets, rather than on a certain knowledge of costs.'[1]

While some small firms decide to order new equipment almost entirely on hunch and with a minimum of paper work[2] we can be sure that other small, and many big firms have cost comparisons drawn up in a standard form for consideration by those responsible for deciding investment priorities. In our own comparatively narrow experience, the content of these forms differs greatly between firms—how greatly over industry as a whole, a separate study could usefully determine. But, despite their important differences, they consist essentially of two (or more) sets of figures: one representing the various costs incurred by continuing to use existing equipment, and the other(s) the corresponding estimated costs if new equipment is installed and used—the totals of cost being reduced to comparable terms on the basis either of annual production or of all foreseen production.

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[1] D.S.I.R., *op. cit.*, p. 45.

[2] The view expressed by Pollock (*Automation*, 1957, p. 224), that 'the man of daring and imagination who relied on hunch supported by experience has become a technological casualty', is a wishful fallacy.

The main items in formal comparisons of costs are: capital cost (sometimes including installation cost), represented by a figure for depreciation; direct labour; direct materials; and overheads. These schedules are naturally rather summary, since if firms attempted to cover every possible direct and indirect cost on a single standard form, the form would be too unwieldy to be of use. The bare minimum of figures entered on these standard schedules has therefore often to be supplemented by explanatory notes; but even the figures themselves prove on examination to be, in greater or less degree, subjective, arbitrary, or potentially inaccurate (although, in so far as the ' errors ' are common to both sides of the comparison, this does not mean that the exercise is without value). One might think that past experience could be accurately recorded; but it would be a very great labour to keep detailed records of the actual or ' historical ' costs of every process over a long period—if this meant, for instance, keeping a precise account of every minute and ounce of toolmakers' and toolsetters' time and materials which had been devoted to the process. Moreover, any particular period taken will include some ' abnormal ' interruptions (breakdowns, etc.) or accelerations (rush orders) of output, or ' exceptional ' runs of ' special ' products—which may be held to invalidate ' true ' comparisons. Standard costing procedure, primarily intended as a control device, is therefore pressed into service; it certainly tends to iron out ' abnormalities ', but is inevitably time-lagged and cannot take account of changes which look temporary but are to prove permanent.

If the past is partly unrecorded, the future is largely unpredictable. How, for instance, can adequate allowance be made for the cost of ' de-bugging ' or ' de-snagging ' new and untried machinery? What fluctuations in the prices of raw materials, what wage changes, should be anticipated? How soon is the new process going to be superseded? Is anyone likely to find alternative uses for the new plant if demand changes? Obviously the presumed costs of operating a new process can only be estimates based on assumptions backed by hunch.

Part of the justification for installing a new process is likely to be the immediate ' saving ' in direct labour, and this may well be accompanied by an expected saving in direct materials. The required quantities, if not always the prices, of labour and materials can usually be forecast fairly accurately. Often however the material fed into highly-developed machinery has to conform to tighter specifications in respect, say, of malleability and size than with older plant where craftsmen were on hand to make adjustments; and this may involve such expensive quality control or special production arrangements by suppliers as to offset much of the anticipated saving. As regards labour, there is not only the possibility of misjudging the type of labour required or the extent of training which will be needed, but the nature of automatic processes tends to introduce a rigidity into wage payment which could prove unexpectedly costly (even though wage payments as a whole form a smaller proportion of total costs than before). Under systems of payment by results, wages are to some extent geared to output; but payment by results is suitable only in so far as workers set the pace. The more automatic the process, the more the pace is set by the machine, and the more reasonable it is—as the Americans have been discovering—for workers to be paid by time. For this and other reasons, wages tend to become a fixed charge irrespective of output:

> ' a plant into which automation has been (wholly or largely) introduced does not enjoy the same freedom to meet a fall in demands for its products by reducing its staff as does a firm in which the bill for wages and salaries forms a very high proportion of its total production costs. In an automatic plant on the other hand wages and salaries are a relatively minor item. Most of the workers . . . are engaged in supervising and in repairing automatic machinery . . . where services are required even if the plant is producing only a fraction of the goods that it could produce if it were working to full capacity. Moreover in an automatic factory—as distinct from a works run on traditional lines—the workers are a sort of ' capital investment '. Some . . . have been trained by the firm. Even if they had contracts which allowed the firm to dismiss them at short notice it would be most unwise for managements to do so because when normal production was resumed it might be difficult, if not impossible, to start the plant going again since suitably qualified operatives might not be available. . . . It is now generally accepted that, in an automatic factory, most of the wages bill is now regarded as an item of ' fixed costs ' (capital expenditure). Traditional methods of business accounting are having to be adjusted to meet this new situation.'[3]

The difficulties of calculating indirect costs are naturally greater: in assessing overheads, practice differs widely. These may be reckoned in the crudest possible way, as a fixed percentage of direct labour, or they may be broken down to show a very mixed bag of indirect costs (supervision, fuel, maintenance, insurance, etc.). The ' fixed-percentage ' method, still widely used, is a rule of thumb which has the sole merit of simplicity.[2] It is obviously

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[1] Pollock, *op. cit.*, pp. 197–8.

[2] One of the large firms we visited did in fact cost a new process in this way. The procedure makes labour-saving machines look increasingly attractive, but after a while the firm may well become concerned if production does not go up—so that aggregate overheads look more and more formidable.

reasonable enough to allocate overheads to a department (or a process) in proportion to direct labour if in fact the cost of direct labour bears approximately the same relation to indirect costs in all departments. But if a department is to be re-equipped in such a way as to reduce greatly the proportionate weight of direct labour, the fixed-percentage method is misleading. For to re-equip a department with labour-saving processes will automatically reduce the share of overheads charged to it, even though it may in fact be incurring far more indirect expenses (*e.g.* in maintenance and technical supervision) than previously. This is one way in which an accounting procedure can distort the issue by representing the savings to be expected from an innovation in too favourable a light. Some of the cost accountants with whom we discussed this point agreed, but saw the problem as one of finding an alternative ' base ' preferable to that of direct labour, although similar objections apply in degree to the use of any single base: ' rule-of-thumb methods of allocating overheads can be grossly misleading when used in estimating the real cost of alternative methods of production.'[1] Some firms therefore adopt more elastic and sophisticated procedures, taking different factors (floor space, power consumed, etc.) into account for different departments or processes. It is certainly difficult to find a workable approximation to the actual indirect costs incurred by each process or set of processes, striking the balance between reliance on the established routine which is doomed to mislead, and a perfectionist quest for accuracy which would be impossibly time-consuming and expensive. Again, as re-equipment with highly automatic machinery is likely to involve comparatively heavy capital outlay, the sums set aside for depreciation will probably represent a larger proportion of the estimated costs of output than was true of the (*ex hypothesi*) more ' labour-biassed ' process which preceded it. The amount by which the capital cost of machinery is written down every year is, however, often arbitrary: it will depend on the tradition of the industry and the custom and practice of the firm (' we always reckon to write off all our machines over ten years '), and will probably have little relation to the expected life of the particular machine, or to its scrap or replacement value, or to its estimated freedom from obsolescence.[2] Wear and tear, normally one of the main determinants of depreciation, becomes more difficult to predict in an inventive age because people have no experience of the new machines; but it also loses some of its importance as a factor in depreciation relative to obsolescence. A machine may become obsolete either because a better machine is available to do the same job, or because its product is superseded—although if the machine is versatile, product obsolescence will not necessitate scrapping, but merely (say) re-tooling and re-siting. Obsolescence, always hard to predict, becomes harder still in a period of rapid innovation, since inventions may have new and unexpected applications in industries other than those for which they were designed. An acceleration of the rate of invention increases the likely frequency of particular machines getting out of date. However, it is obviously impossible to keep up to date everywhere—*i.e.* always to have bought the latest type of machine for every purpose—if only because rapid and continuous technological advance would reduce the production lines to chaos. Thus the effort to avoid obsolescence involves not only the selection of the processes where innovation is most attractive on grounds of comparative technology and comparative costs, but also the timing of proposed changes so as to give the greatest benefit in respect of opportunity cost.

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[1] D.S.I.R., *op. cit.*, p. 59.

[2] Depreciation as estimated in this context does not, in practice, necessarily correspond with the sums entered under the heading ' depreciation ' in the firm's accounts, as the latter are scaled in such a way as to get the greatest advantage from income-tax allowances.

It is in order to get some idea, not only of the multifarious direct and indirect costs involved by decisions to make industrial processes more automatic, but also of how far and at what stages managements are able to take these costs into account, that this study has been undertaken. Ideally, such a study should rest upon a critical assessment of the techniques available to, as well as those used by, the firms in question; upon a scrutiny of their relationship to their markets and of their adaptability to changes in demand; upon an examination of the adequacy of their accounting procedures in this special context; and upon a judgment of the even more important procedures which underlie their decisions to innovate. In many of the more fulsome anticipations of the Age of Automation, these practical matters have been neglected. So limited a study as this could hardly pretend to do them justice, although it could do something to clarify their implications.

Parts A and B of the study are almost entirely descriptive, and the more general questions arising are taken up in Part C. Economists may well become somewhat impatient at the length and detail of this preliminary discussion of engineering processes; but their own generalisations in this field are apt to carry little weight with industry, especially if these generalisations are difficult to apply to the sort of problems that confront manufacturers day by day. For this reason it seemed better to us, as a corrective, to err on the side of being over-specific, in the hope that some awareness of practical problems might commend the later and more general discussion to those who are actually engaged in the process of industrial innovation.

A. INDUSTRY, FIRMS AND TYPES OF PROCESS STUDIED

The industries most discussed with reference to automation have generally been those which deal with fluids in bulk, like the oil and chemical industries. It seemed more interesting to study those where advanced mechanisation was still being introduced or could be introduced: in particular, industries where there were technical problems of small batches, of the handling of tricky components, and of awkward assemblies. These problems all arise in light engineering, and indeed this industry is one where the problems of mechanisation appeared most challenging. We therefore decided to begin by examining selected processes in three firms manufacturing electrical equipment of various types. Electrical equipment making should not be considered as too special a case of light engineering; after all, as an engineer in one of the firms put it, the electrical character of the products comes in only at the designing stage; after that, the problems are esentially those of light engineering in general.

All three firms are ' progressive ' in the sense that all of them are interested in keeping abreast of technical developments. Two of them are very big, by any standard; but, partly because we felt that decisions to invest in new equipment might well have a different character in firms of different sizes, we were anxious to include a relatively small firm in our enquiry. We also wished to get a summary view of the main metalworking processes and, since these include casting as well as pressing and machining, we extended our study to include foundry work—which involved visiting a large modern foundry in addition to our original three firms. In the course of our examination we found it necessary to talk to certain machine-tool firms and their agents, as well as some of the relevant professional and technical associations (the Institution of Production Engineers, the Production Engineering Research Association, and the Institute of Cost and Works Accountants).

In the firms we visited there were of course very many different types of process; and of these we selected a few which we thought would illustrate the problems we were studying. Our account is thus centred on the processes, but we must start with a brief description of the three firms in order to give the setting.[1]

Black's

This large group of companies manufactures a wide range of light engineering products. The factories which we visited, situated in an industrial area, are concerned with fairly small complete assemblies intended to be incorporated by other manufacturers in larger pieces of equipment. The firm is well accustomed to visits from research workers and others. The main concern of the firm, as explained by the chief production engineer, was to make things faster ' and therefore cheaper '. He showed us charts giving summary measures of labour productivity. Labour productivity figures of one kind or another were used throughout the firm as important indicators of efficiency. The firm's policy was not, in a time of full employment, to expand the labour force, but to keep it more or less constant while steadily raising the productivity of the existing operatives. By this means they hoped to keep pace with a fairly continuous expansion of demand for their products. For some of these, the customer firms were reluctant to permit changes in design; for others, related to fashion, the customers really dictated the design, without regard to the economic consequences for the producers. Whether or not designs were liable to change, the firm pressed on with mechanisation and the consequent increase in labour productivity. Charts indicated that, while their labour productivity after the war had been less good than that

[1] The technique of carrying out such case-studies is not new: a chapter of Babbage's book ' The Economy of Machinery and Manufactures ' (London, 1832) is devoted to elaborating it.

of some other firms, it could now face comparison with the best international standards.

Because innovation was constantly going on, the firm both bought a large amount of equipment from outside every year and maintained a development section of its own in which new machines were designed and brought to levels of performance adequate for production. The burden on the Board of considering these innumerable items of investment had become so great that a more systematic procedure had had to be evolved for approving decisions. This procedure had been codified into a set of forms and an explanatory booklet for the guidance of the engineers and accountants concerned. This booklet epitomised one aspect of the firm's philosophy—at least in those factories with which the author of the booklet was concerned and in which we ourselves were interested. The main stress is put on the utilisation of plant, albeit mostly within the limits of single-shift working.[1] The author insists that it is a weakness to have ' banks ' of idle plant merely as a safeguard against breakdowns or other unforeseen events;[2] one of the firm's engineers summarised this view by saying ' low utilisation pinpoints inefficiency '. (On the other hand there seemed to be no objection in principle, either in the booklet or in the practice of the firm, to having ' banks ' of half-finished components;[3] where these were considered necessary to allow flexibility in the timing of successive operations, a continuously circulating conveyor was often used on which parts were stored after the first operation until they were needed for the second.) But, he states, utilisation—in the sense of merely keeping machines running—is not enough: the utilisation must be ' effective '—*i.e.* the speed of running, technique of feeding the machine, etc., must be designed to give the maximum output per unit of running time. Stress is also laid on other causes of low effective machine utilisation—ordering new machines prematurely or uncritically, making over-generous allowances for scrap, paying too little attention to the possibilities of shift working, and so on.

We first obtained a general view of the processes employed in two of the firm's factories—one an older building, which was however constantly being re-equipped, and the other both new and up-to-date in its equipment. We finally selected for study the processes of transfer pressing and hobbing.

Green's

Green's, like Black's, is a large group of companies making a fairly similar range of light engineering products which are sold to other manufacturers for further assembly. The factory we visited was many miles from the firm's headquarters: it had been set up some years before in a small town which had previously had only one industry of any size. The work-people therefore had to be recruited from the surrounding countryside. The re-equipment of the factory, which had gone on fairly continuously, had been well publicised as an instance of ' automation ', and we went to see it for this reason. In fact, as often happens, the most completely automatic section of the factory had been running for some time, and the excitement was mainly about the rearrangement of an orthodox production line with many operators and the inclusion in it of new automatic equipment. This arrangement had been associated with an appropriate redesign of the product. One or two other changes in methods had also been carried out. One of the principal products was a relatively new venture, but the market had expanded much more rapidly than had been anticipated. Now, the firm expected output to rise steadily, although because of the dominant place it had taken as employer of local people it had had to give some guarantee of holding its employment constant. It had also undertaken to try to widen the range of its products locally in an attempt to protect its workers from the hazards of trade.

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[1] Only a few departments (*e.g.* the press shop) worked two or three shifts. There is little tradition of shiftworking in the engineering industry. The reason usually given (as in this firm) is that shiftworking runs contrary to established local custom. However, another reason may be that the alternative of intermittent overtime allows more flexibility in dealing with varying output requirements.

[2] Contrast this attitude with that of Brown's (p. 144).

[3] Contrast this attitude with that of Green's (p. 142).

The firm has a very different method of deciding on new processes and equipment from that of Black's. The chief production engineer has his own office and development plant near the firm's headquarters; and managers of particular factories were allowed—and indeed expected—to call on his services in order to increase the efficiency of their plant. Thus, although he had no direct control, the factory now strongly reflected his philosophy of production. He insisted on the ' momentum ' of production—*i.e.* on the necessity of a completely integrated line with no ' banks ' of unfinished components between operators. This implies that any breakdown, or slowing-down, in a process is ' recognised as a group responsibility ', and that ' the maximum pressure is exerted by everybody to get things moving again '. By keeping up the momentum of production in this way, and by constant attention to layout of equipment and the disposal of stores (' good housekeeping '), he hoped to save much space—which he considered of crucial importance both on grounds of economising on overheads and in order to combine compactness and ease of control with an ever-expanding output.

The idea of a fully integrated production line without ' banks ' was not completely acceptable to everybody we met in the factory, at any rate on the staff side. Minor breakdowns, they thought, involved disproportionate worry. Some of them also favoured the isolation of certain pieces of equipment of the same type—*e.g.*, heavy presses—in a special shop of their own, even at the cost of extra transport of components—not only so that they could be maintained and minded economically by people familiar with them, but also so that they might be used for a wider range of purposes than that of merely feeding the particular line in which it had been decided to install line.

[1] This last problem (vertical integration *versus* specialisation) has always been with industry at various levels, and has been solved in all possible ways: *e.g.*, some motor firms prefer to buy their components out from specialist manufacturers who also supply other motor firms, while others make nearly all their own equipment.

However, the philosophy of the chief production engineer was exemplified in the factory in the manufacture of one of the more important parts. Production of this part had largely been consolidated on to a ' single ' line. This line consisted of pallets moving continuously on a long conveyor; but components were taken off these pallets at many points for processing or partial assembly and then replaced. Some of these processes were necessarily major operations—small lines in their own right. The main effect of the conveyor was to exert a continuous pressure on the operators to keep pace with it. In spite of this, ' banks ' could accumulate at the end of a few of the subsidiary processes, and the pressure was not so heavy at these points. This arrangement of a single line with processes being carried out alongside depends essentially on having a large number of operators, since every process involves having operators to remove and replace components on the line.

' Momentum ' appeared to us to be a rather general concept covering a variety of different ideas, which included for example that of continuous pressure on operators, of the smooth and easily controlled flow of parts moving down the line, of the absence of stocks (whether or not in a part of the line which was fully automatic), and of the economy of space.

A transfer press—which seemed to provide the chance of a comparison with Black's—had been put in as part of the line. Other processes in which we were interested included a special-purpose painting plant and a general painting and finishing shop.

Brown's

Brown's is a small firm compared with the others; it employs less than a thousand people in a single factory, in a medium-sized town containing some other well developed industry. It is of the family firm type and, in essentials, is under the control of one man. We have sometimes been tempted, in the interests of convenience, to personify ' the firm ' when writing of Black's and Green's, although there was much interaction of view between different people and departments; but in the case of Brown's there is little interaction of this kind since the head of the firm is able to supervise the operations of the firm as a whole.

The firm has prospered and expanded, particularly since the 1939 war. The factory has remained on its site and has therefore been built up and added to piecemeal: in consequence, the layout of the buildings now appears to the outsider as compact but confused. Originally, the firm was centred on a forge, and then on an iron foundry; now, they are general electrical engineers, with the foundry supplying components to the factory. The firm had gained experience in its present type of work during the 1939 war, using machines supplied by the Government. Unlike Black's and Green's, Brown's turn out complete products, not components for incorporation in the products of other firms; but the customers of all three are other concerns rather than final consumers. Brown's have only three competitors, all of them very large firms with a far greater command of resources, more extensive marketing organisations, and possibly a bigger fund of technical advice. However, the articles made by these firms to compete with Brown's main products represent only a small fraction of their total output, and Brown's reckon that they probably receive less attention than they would if they were a more important part of the firms' production. Two of these three competitors are high-cost firms, and the prices which enable them to meet their costs give the remaining firm, and also Brown's, a very handsome margin in the same market. Brown's managing director claimed that his costs were certainly as low as those of his most efficient competitor, and that he had an extra pull in being willing—as none of the others were—to undertake small batch production to order. This, in fact, was how his business had been built up before the war,. However he did not think he could expand his sales by undercutting his rivals: they were ' sleeping dogs which it is wiser to let lie '.

Whether or not because of their policy of batch production,[1] Brown's had little mechanical handling equipment such as conveyors or fork-lift trucks. On the other hand they were well equipped with machines, some of which were very modern and fully automatic: indeed, there seemed to be a good deal of excess machine capacity.[2] Because the firm had had to expand quickly since the war, and had gained by it, they felt that it was necessary to prepare themselves for any further expansion that might be called for—even if the new demand were for a greater variety of products than was now being made.

The firm tended to employ the young and the old: there were boys working in the toolroom (Brown's believed that they could be assured of skilled labour only by training their own), and quite a large sprinkling of pensioners on light repetitive jobs. Brown's did not like ' superfluous ' paper work,[3] and their costing methods—at any rate in the foundry—tended to be simple, with the rough-and-ready assumptions that such simplicity necessitates. Moreover, since they costed products and not processes, we could not get the sort of data which Black's and Green's provided. However, the distinction is not a wholly rigid one; for foundry products were costed separately in some respects from the products made elsewhere in the works, and what is made in the foundry is, after all, made by a single process. The foundry had been fairly recently re-equipped, and it was in fact in this re-equipment that we were interested.

B. PROCESSES[4]

(*a*) TRANSFER PRESSING

Presswork has been a standard operation for many years. Fifty years ago, ' all the basic types of presses were available and a good deal of other machinery for manipulating sheet metal. . . Mechanical presses in those days were very like the modern machines in form and general design'. A most important difference seems to have been that 'presses fifty years ago were looked upon as highly dangerous machines, as they were in fact. . . . Firms were even known to place their work out with shops to avoid the responsibilities of having presses on their own premises. There is certainly a very different state of affairs to-day. It is due largely to the much greater reliability of presses, to the changed outlook of management, to the contribution made by guard makers, and, no doubt, to persistent factory inspectors'. Presses last a long time: we were told of cases where heavy presses had only recently been scrapped after fifty years of service. In just the same way, fifty years ago 'the actual machines used in the shops were often far from modern, even by 1900 standards.'[1]

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[1] Batch production was described to us by the Secretary of the Institute of Production Engineers as highly characteristic of British industry.

[2] Their attitude to utilisation was clearly very different from that of Black's.

[3] They kept a minimum of ' running ' records, although they stated that they were always ready to undertake special studies if the need arose.

[4] In this section we shall be dealing with subjects which are familiar enough to engineers, or to accountants, or to economists—but not necessarily in every case to all three. We have therefore thought it advisable to ' spell out ' our concepts, at the admitted risk of occasionally irritating different readers in turn.

These were single-blow presses. A transfer press consists essentially of a number (usually from 4 to 14) of single-blow presses compactly and inseparably arranged in a single frame. The transfer between the 'stations' is automatic. But transfer presses, although publicised in recent automation literature as one of the manifestations a of new industrial revolution, also have a history: a catalogue of one of the leading German manufacturers (Schuler) illustrates a small transfer press which was being made in 1900. However, modern transfer presses of the type in which we are interested are large machines capable of moderately heavy work.

The arrangement of the presses within the frame is either in a straight line (as is most common) or in a circle (as in a recent Italian design made by Benelli-Gavazzi).[2] In the straight-line type the transfer is achieved by the 'cakewalk'—or back-and-forth—motion of two large arms equipped with fingers which grip the components at the beginning of the forward part of the motion, carry them to their new stations, release them, and then go back to start a new cycle. In the circular type the transfer is achieved by the 'merry-go-round' principle; the component being gripped by the same fingers throughout its journey and being released only temporarily at each station while it is actually being pressed. Because the machine is circular, the fingers rotate continuously in the same direction.[3] Naturally, special advantages are claimed for each type: the circular type is claimed to be lighter and because it does not have to reverse its motion—quicker, while the straight-line type is claimed to be more accessible for maintenance and tool-changing. Straight-line presses are of different kinds, not all having the 'underslung' drive favoured by IWK;[1] the presses are made by different firms, and we are in no position to judge their respective engineering merits. All transfer presses can work from large coils of strip metal needing fork-lift trucks to move them around (in which case the first station is devoted to 'blanking'—*i.e.* cutting the discs for subsequent shaping), or they can have an attachment enabling them to work from ready-made blanks which may be fed either manually or by machine. Those we saw worked from strip. Some engineers consider it better practice to work from blanks made on a separate machine, because blanking is an operation which takes up much of the pressure available in the press. Thus the alternatives are either to have a blanking machine, a lighter transfer press, and an arrangement for carrying the blanks between them or, for the sake of compactness, to use a transfer press heavy enough to stamp out the blanks as well as to do the subsequent shaping.

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[1] These passages are quoted from an article on power presses in the 50th anniversary number (April 15th, 1950) of *The Machinist* (now *Metalworking Production*), p. 575.

[2] All the transfer presses we have seen were made abroad. Imported machine tools are liable to a 17½ per cent duty, which may however be waived if there is no machine of an equivalent type, weight, and capital cost produced in this country. For some years after the war, all imported transfer presses were allowed in duty-free. The Benelli-Gavazzi press still is; but, as British manufacturers have announced their intention of producing presses of the straight-line type, such presses are now paying the duty.

[3] A circular arrangement of five single-blow presses, fed by a 'spider' at the centre, is illustrated in R. H. Macmillan, *Automation—Friend or Foe?* (1956), p. 24. This is a clumsy and space-consuming affair compared with the specially designed Benelli-Gavazzi press.

A transfer press, for all its compactness, can clearly be a large and inflexible piece of equipment. A device for feeding the press at two or more points simultaneously enlarges its scope, so that it can make more than one component at a time. Multiple feed has been a feature of the circular type of press, and the straight-line presses have also been adapted for feeding at both ends and ejecting in the middle. An American solution (that of the Clearing Machine Corporation) is to design transfer presses on the unit principle—*i.e.*, to plan two or more sets of rather shorter presses (say with two or three stations apiece) so that they dovetail neatly together, working off the same drive with their transfer mechanisms completely interlinked. These units can be rearranged in groups as necessary.[2] It should be added that these presses are heavier than the German and Italian types mentioned.

What then are the alternatives to transfer presses? An eight-station transfer press, for example, will generally be used in place of eight single-blow presses (or perhaps other machines), each with an operator. In fact, some makers claim that it will replace not only these presses and their operators, but also the annealing machines[3] (and their operators) which may have to be employed between single-blow presses because of the length of time between the metal-working operations. If, as in the cases we saw, the transfer press is working from strip metal, it will need only a single machine-minder to keep an occasional eye on the press. (In fact, the work-study engineer in one of the other firms using transfer presses thought it might have been a good idea to allow his machine-minders to read books, if only to keep their minds alert enough for the occasional glance.) Thus, on such a comparison, the transfer press is a classic example of the labour-saving

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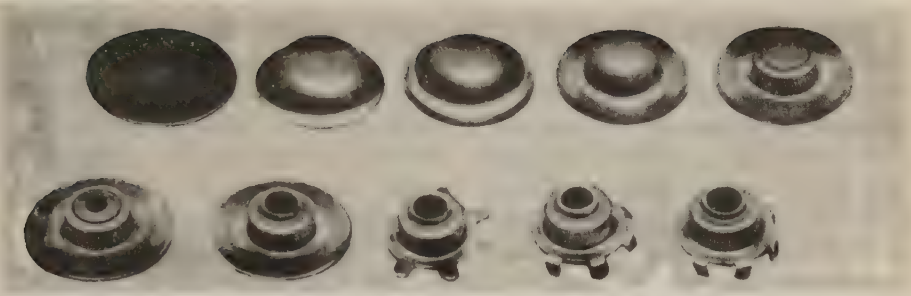
[1] There is a division of labour between the IWK (Industrie Werke Karlsruhe) Company of Germany and the Verson Corporation of America: the former makes transfer presses of up to 315 tons total pressure on all stations, and the latter makes similar presses of up to 3,000 tons total pressure.

[2] See, however, p. 194.

[3] Annealing is a heating treatment to stop rapid physico-chemical changes, and consequent weakening, in the material.



(*From a maker's catalogue*)

SUCCESSIVE STAGES OF A COMPONENT AS IT PASSES THROUGH A SINGLE TRANSFER PRESS

[TO FACE PAGE 146

machine. But this is not the only comparison possible. Many components made on transfer presses could alternatively be made by, for example, diecasting[1] or by impact-extrusion[2]—very possibly with some difference in respect of raw material and quality. These processes may also necessitate some change in design, in so far as they are not well adapted for dealing with re-entrant angles.

However, the direct comparison of a transfer press with a line of single-blow presses has to be carried a little further. The advantages of the transfer press are five: (1) it saves direct labour; (2) it economises in floor space; (3) it possibly produces components more quickly (this is one of the main points made by salesmen); (4) it precludes any necessity of 'banks'—boxes of unfinished components—between the several presses; and (5) it may also save on the lag between the start of the run and the emergence of finished components. (5) is purely a 'pipeline' effect, which becomes less important the longer the run. (4) is also partly a 'pipeline' effect, as these banks are really stored material; but since they also take up space, (4) overlaps with (2). (3) may be illusory: after all, a line of single-blow presses will turn out completed components, once the 'pipeline' has been filled, as fast as the slowest press of the line can move up and down—and this may be as fast as the transfer press can move up and down. (2) and (1) are undoubtedly advantages; but there are disadvantages which have to be reckoned with. As we shall see, a transfer press is more expensive than the equivalent number of single-blow presses; the cost of tools (and a fresh set of these heavy pieces of equipment has to be made whenever a new component is to be produced on the press) is also considerably greater; installation costs may be a big item; and there are others.

Two of the firms which we visited—Black's and Green's—had installed one or more transfer presses, and discussed with us their reasons for the purchase and their subsequent experience. Black's had, as we mentioned above, recently adopted a fairly set form of calculation as a preliminary to decisions to order plant. We saw such a form for a transfer press of around 100 tons pressure; and we also examined a special study of the 'economics' of several of their transfer presses which had been carried out after these had been installed for some time. Green's, with their less formalised approach, had also installed transfer presses; and the chief production engineer (who had largely influenced the decisions) discussed with us the installation of a particular press and kindly wrote some notes for our guidance.

The form used by Black's for their decision to order the transfer press is summarised in Table I. The firm's practice is to have such estimates drafted by an engineer working in an accounts department. The form in which such estimates are made, and the way in which they are used, suggest a number of important questions which we shall be discussing in Part C. For now, we must amplify some of the entries in the form and give some detail about the motives for the installation.

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[1] Diecasting is a method of shaping molten metal in a die of appropriate shape.

[2] This method is generally used with soft metals (or with harder metals heated) to produce thin-walled components.

The transfer press was not the first to be installed in the firm, although the earlier presses had been rather smaller. It was proposed to buy it in order to replace another method which had used three single-blow presses and three lathes, requiring in all 7 operators (5 women and 2 men). These operators were now to be replaced by one man of the same grade of skill—though he was to be a machine-minder rather than an operator. The figures for direct labour, and also those for direct materials[1]—in this case, just coils of metal strip—were based on ‘ standard costs ’. Two types of component were being made, and it was assumed that the same numbers of each were to be produced by the new process as by the old. Machine utilisation was put at 80 per cent (on the basis of single-shift working) for both processes. However, a saving in direct materials was anticipated because, under the new process, some of what had previously been scrap from the first component would be used to manufacture the second.

TABLE I

Cost Calculations Before Purchase of New Equipment

Cost of new IWK 9-station transfer press (including special equipment) ...	£20,358
Cost of tools	£4,500
Cost of installation	£2,000
	£26,858

Items affected by change of process	*Costs per year (£) as anticipated before purchase* (*a*) *old method* (*4 heavy and 3 light single-blow presses*)	(*b*) *new method* (1 *IWK transfer press*)	(*c*) *saving* + or −)
Direct labour (including wages, National Insurance, holiday pay, etc.)	3,229	465	+2,764
Direct materials	15,575	14,988	+587
Overheads:			
Maintenance: machine labour	538	678	*−140*
materials... ...	108	136	*−28*
tools labour	298	498	*−200*
materials... ...	60	100	*−40*
Power, etc.	148	202	*−54*
Depreciation	185	1,018	*−833*
All above items	20,141	18,085	+2,056

Saving as percentage of capital cost ... ... £2,056 on £20,358 = *10%*

At first sight it seems paradoxical that, although the firm had been running the old process and had also used transfer presses, the costs could not be calculated directly from records of actual experience. But it is difficult to keep detailed records of when maintenance men have to attend particular machines, and of how much oil and other materials they use. This means that the figures for machine and tool maintenance have mostly to be built up from a series of assumptions. Similar difficulties often arise in industry: the cost of keeping, or even finding out, precise details of everything that goes on (not only of maintenance, but also of the time and trouble of managers, supervisors, designers, engineers, accountants—and even sometimes of such items as power, light, gas, etc.) can often be prohibitive. Again, the estimates given in the table for the new press are based on the assumption of smooth running. In fact, most new machines have teething troubles and may need a lot of supervision and adjustment, as well as wasting time and material in the production of scrap. Such costs of ' de-bugging ' are, from one point of view, capital costs—like those of installation. In our experience they have sometimes tended to be high in the case of transfer presses, where experts on the staff of the German manufacturers have had to be flown over to cope with breakdowns.

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[1] The method employed was to estimate the material used, in both cases, from the design and not from records of actual usage.

A different kind of problem—a problem of concept rather than of cost—is posed by depreciation. Firms put aside, notionally at any rate, a sum every year (the depreciation allowance) for each of their machines, in order to smooth out the lumps of capital expenditure involved when they are worn out or no longer needed, and are to be replaced. This annual sum is counted as an expense of having the machine, which is incurred whether the machine is used or not. There are many ways of deciding what it should be, depending on the attitudes of management and the situations with which they have to cope in an age full of uncertainties.[1] A simple rule of thumb is to estimate (perhaps merely by a convention) the expected useful life of any machine when one buys it, and then, if for example there is an expectation of ten years, to put aside one-tenth of the purchase price every year.

At Black's the conventional life of presses is 20 years. The firm paid £20,358 for its transfer press, and therefore proposed to lay aside £1,018 a year for depreciation. Surprisingly, they did not include the cost of tools; although such an omission would be strictly correct only if the cost of retooling the old set of presses for the new components happened to be the same as that of tooling up the new transfer press. (However, we noticed that later studies were treating tooling costs carefully.) The cost of installation was also omitted from the comparison, although the installation of a big transfer press may involve building massive concrete foundations and possibly concrete pits. Thus with some ' underdrive ' transfer presses the whole of the driving gear, clutch, etc., are mounted below floor level; and an instance was quoted to us by one of the suppliers of transfer presses where a firm had to install a deep scrap bay with conveyors beneath the presses before the latter could be put in.

The depreciation figure for the old process was arrived at by the firm as follows. The old presses had been bought some time before, but the full sum for their depreciation had not yet been set aside. The ' unrecovered ' part of the sum (£3,700) counted, not as a bygone, but as a charge which would still have to be paid; and to meet it £185 was to be set aside every year for the next twenty years. The fact that the firm was willing to do this illustrates how conventional are the estimates of age used in depreciation calculations. Note that the 10 per cent saving is reckoned on the cost of the new press only: the cost of tools and the cost of the installation are excluded. *If* it were in fact true that tools of the same cost would in any case have been required for the old presses, their omission from the capital cost would be valid, since the percentage should be calculated only on the extra capital cost involved in the decision to buy the transfer press. The omission of the installation cost cannot however be justified in this way.

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[1] This question will be taken up in Part C.

The comparison of costs for the old and new processes is on an annual basis, and in order to make such a comparison one must obviously consider identical outputs—two different methods of doing the same job.[1] The figures of utilisation (80 per cent in both cases)[2] are presumably intended to provide supplementary information only, and in no way enter into the calculations. In this instance we were told that the utilisation of the single-blow presses had in fact been about 30 per cent; but the firm was reckoning, on very convincing grounds, on a big expansion of output. However, after the new press had been installed, the firm's customers unexpectedly changed their demands in such a way that the components for which the press had been ordered had to be diecast and not pressed at all. For some time it was difficult to find another extensive use for the new press, and its utilisation had been barely 4 per cent;[3] but eventually other work was found. In the meantime the firm had thought it advisable to undertake special studies of the 'economics' of transfer pressing. The director who had been responsible for the guide (mentioned above)[4] for engineers ordering new equipment had asked for these studies to be made. He pointed out that the 'high productivity rate' of the press would tend to make line production more difficult and, presumably with the idea that the press ought to work for several lines, he first asked for a routine to be evolved for a rapid changeover of tools. This routine, which was produced by Work Study, involved the mounting of all tools on a block of metal—known as a 'bolster' or 'platen'—which can be slipped into the press as a single unit.[5] Since in this case the weight of platen and tools came to nearly two tons, a heavy fork-lift truck had also to be specially ordered.[6] The director further pointed out that, while it would probably be fairly simple to justify the press on grounds of labour productivity,

[1] See however p. 116.

[2] It seems unlikely that, for a given output, the utilisation percentage could have been identical for both processes, since transfer presses can usually be expected to work at any rate a little faster.

[3] This kind of inflexibility has caused difficulties before now: an advertisement for the Clearing 'modular' transfer press says 'Here's a veritable monster of a press that can never become a white elephant. . . . Modular press construction is a Clearing innovation that makes it entirely practical to automate the production of large-scale parts without fear that future changes in models will render the press equipment obsolescent.'

[4] See p. 141.

[5] On this press the accepted method had been to change tools individually; and the firm therefore got the manufacturers of the transfer press to design and make the platen. As a result, platen-changing may by now have been adopted more generally. One objection to platens, which we heard raised, is that they do not allow tools to be adjusted to cope with variations in the quality and thickness of material. The press manufacturers' reply was that firms really ought to be more exacting with their material suppliers.

[6] It cost £4,000; but fork-lift trucks are always useful.

the 'economics' might prove a little more difficult. The difficulties remained unsolved. Two years later he was still dissatisfied with the utilisation of the press, and called for more detailed studies to be made. These studies were not confined to the particular press which we have been considering, but data were obtained for several transfer presses of different sizes which the firm had acquired, and comparisons were made with several differently-composed sets of single-blow presses. The work, which was done first by an accountant and then by an engineer, was still being developed at the time of our visits.

At first a tabulation was made in terms of labour productivity and utilisation . A few weeks later, a preliminary report was produced with the following conclusions:

1. 'The economics and direct labour productivity of these (transfer) presses compare favourably with single-blow presses.' (Direct labour productivity was about six times that of the corresponding number of single-blow presses.)
2. 'Economically, transfer presses require high utilisation and low tool costs to justify their existence. At the present utilisation the transfer presses are slightly better than single-blow presses.'
3. 'Additional suitable jobs in the particular shop are difficult to find. Additional work may have to be found from other products.'
4. Quicker tool changing, and cheaper tooling, needed further consideration: 'There is no doubt that the dominant factor is the present complex and expensive tooling. For large capacity transfer presses to be an economic proposition, tooling must be simplified and standardised and the cost and change-over time must be little more than when using single-blow presses.'

As regards tool-changing, all the transfer press manufacturers said that this should be quick (60 to 100 minutes, one of them maintained). However, the toolsetters we met had been rather less fortunate: one of them had found that the changing of each tool separately had taken as much as three days in all. This had been the reason why Black's had decided to experiment with a platen. Incidentally, these heavy platens take up much space in the tool store—which partly offsets the compactness of the transfer press on the factory floor.

The makers of transfer presses admit that tool costs are relatively high. One of them put the cost of transfer-press tools at between 20 and 40 per cent above that of the tools for the corresponding number of single-blow presses. Another put it as much as 100 per cent higher, and illustrated the importance of tool costs by a chart designed to show the 'break-even' point for a transfer press in terms of the number of components which would have to be produced in order to justify using such a press in preference to other methods (Diagram I).[1] The representative of another manufacturer main-

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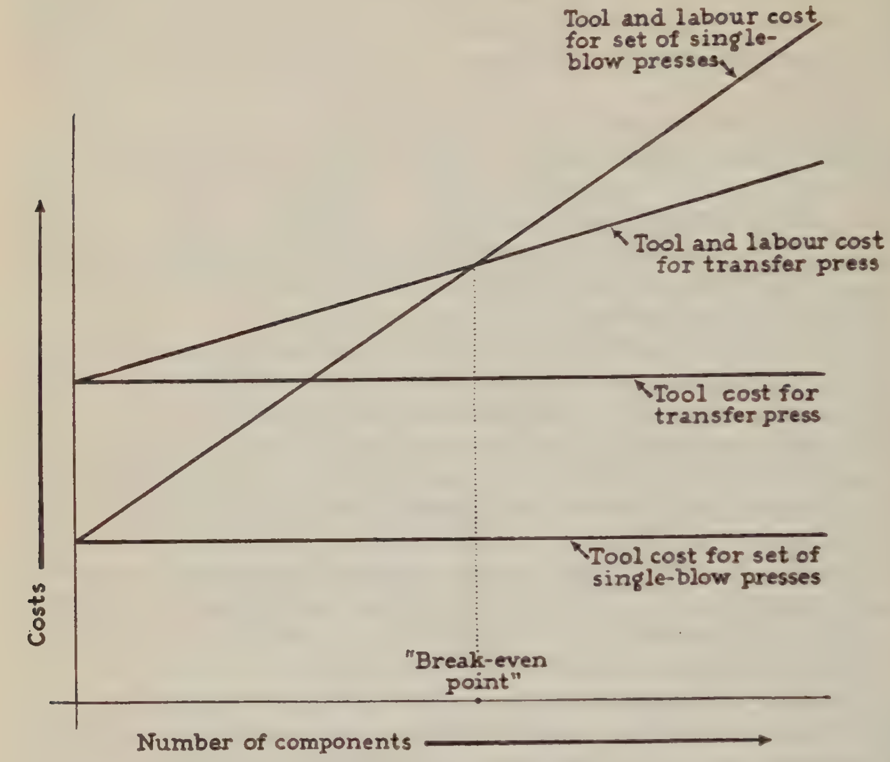
[1] No account was taken of the capital cost of the press: as the representative of another supplier put it to us, 'we don't advise firms on their depreciation policy'. Such a presentation obviously neglects half the problem. It is true that depreciation policy could justifiably vary considerably from firm to firm, and it is understandable that press manufacturers feel this to be outside their province. However, since the omission of any reference to capital cost always produces a bias in their favour, it would have been fairer to include one or two specimen depreciation figures in their calculations.

Diagram I

Economics of Transfer Press[a)]

(Press manufacturers' version)



a) *Capital cost ignored*

tained that, while the cost of tools varied widely, a full set might well cost as much as a small transfer press.[1] The main reasons for the high cost of tools are as follows. There are usually more ' stations ' on a transfer press: *i.e.*, there are more steps in the process than would be the case if single-blow presses were used. A transfer press may do in two stages what a single-blow machine could do in one. (There is possibly something in the makers' claim that the gentler working of the metal improves the quality of the component produced.) Again, it may be convenient, in order to save handling, to put some operations on to transfer presses (*e.g.*, putting a screw-thread on a component) which could be done more simply on a specially chosen single machine (such as a lathe). Thus not only do transfer presses tend to have

[1] Some details of the relative costs of tools and presses are given in Appendix A to this section.

more tools, but the tools tend to be more complex or larger: some of the bottom tools, for instance, may have to be longer than they would otherwise be since all the tools on a particular press have to be the same height. It should perhaps be added that, partly because British industry has not yet got the habit of using transfer presses, tools for these presses are still usually made specially by the manufacturers abroad—although there are signs of a change and some firms are attempting to make their own. In any case, the cost of tools may include the cost of special grippers and feeder fingers, together with that of a platen.

Since tools are so expensive, it becomes important to know how long they will last. Blacks, indeed, had never experienced a case where a tool had worn out, since its customer firms changed their demand fairly frequently; but they estimated that even at the existing levels of utilisation tool life would not exceed 3 or 4 years[1]. Supposing that a set of tools costing £5,000 lasted 3 years, and a transfer press costing £20,000 lasted 20 years, the average yearly amount spent on tools would be larger than the sum set aside annually for the depreciation of the press. However, runs of components produced by particular sets of tools may not continue nearly as long as 3 years, and in such circumstances tool costs may well be dominant. If two or more components are to be made on the press in the same year, then, with the necessary tool changing in addition, tool costs will obviously be heavier still. For this reason the subsequent calculations done by Black's took particular account of tool costs.

Black's accountant argued as follows: If a series of single-blow presses is to be replaced by a transfer press, then—because of the saving in direct labour—the more the press can be used the more can be spent on the tools, whether the tooling is for one or for several components. He therefore produced charts for cases where one or other of the firm's transfer presses was considered as replacing various sets of single-blow presses and other machines; and these charts showed just how far the firm could go in spending on tools and still make the transfer press a paying proposition at various levels of utilisation. (Diagram II is an example.)

This approach reflects the emphasis on machine-utilisation of the original directive. However, if the machine were to be used to produce a variety of components, it would be the tools (expensive as they are) which would spend much of their time unused in the tool store.[2] The next study, carried out by an engineer, was illustrated by a chart designed to show how the cost[3] per

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[1] However, not too much should be made of such figures, since tool life depends on such variables as the material on which they work (steel, brass, aluminium, etc.), the material of which they are made (*e.g.*, cast steel or tungsten carbide), and the quality of the craftsmanship in their making. The vibrations of the press itself, and of the surrounding machine shop, are also thought to be important.

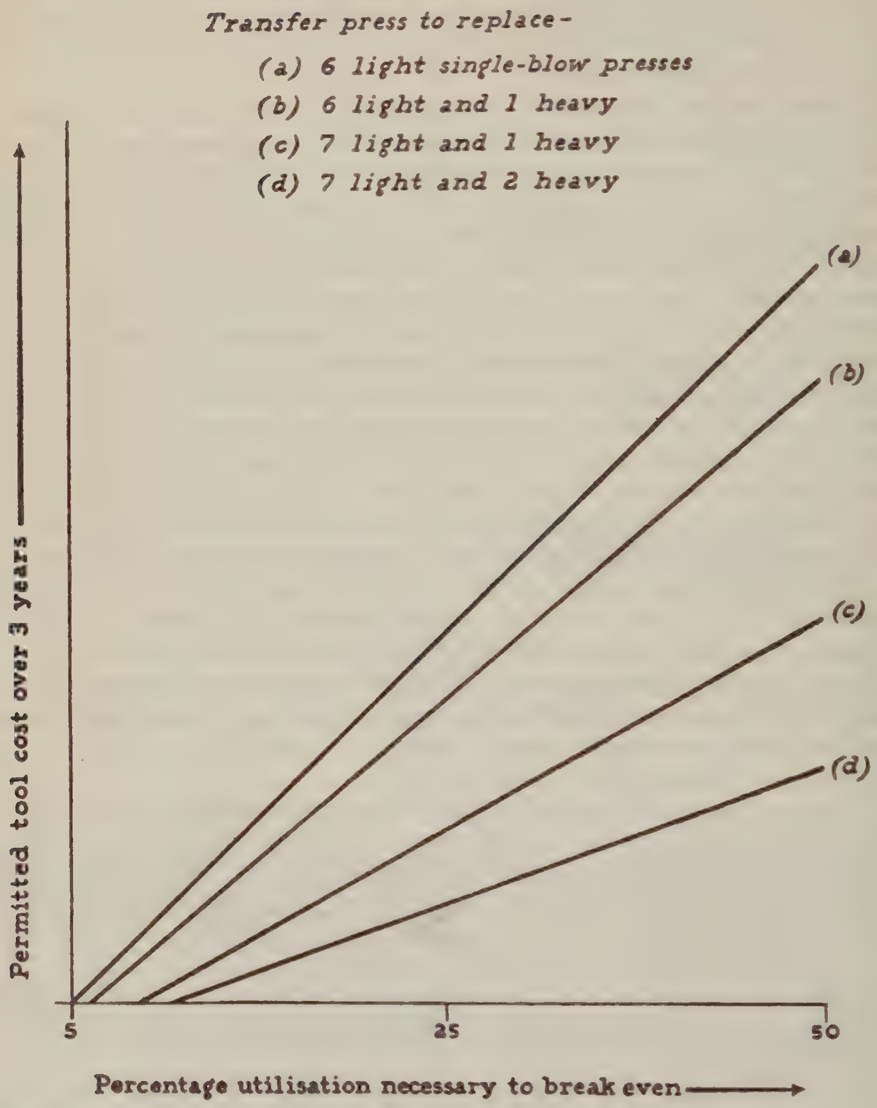
[2] Another interesting example of little-utilised tools is that of patterns stored in the pattern shop (*cf.* J. M. Clark, *The Economics of Overhead Costs* (1937 ed.), p. 118).

[3] These costs included only those which were considered to differ as between transfer press and single-blow press operations: *i.e.*, direct and indirect labour, power, tools, tool maintenance and machine depreciation. (The figures are given in Appendix B to this section.) They do not, of course, represent the 'total' cost per component, as various factory and departmental overheads are omitted.

Diagram II

Transfer Press Utilisation Necessary to Break Even

(Black's first study)

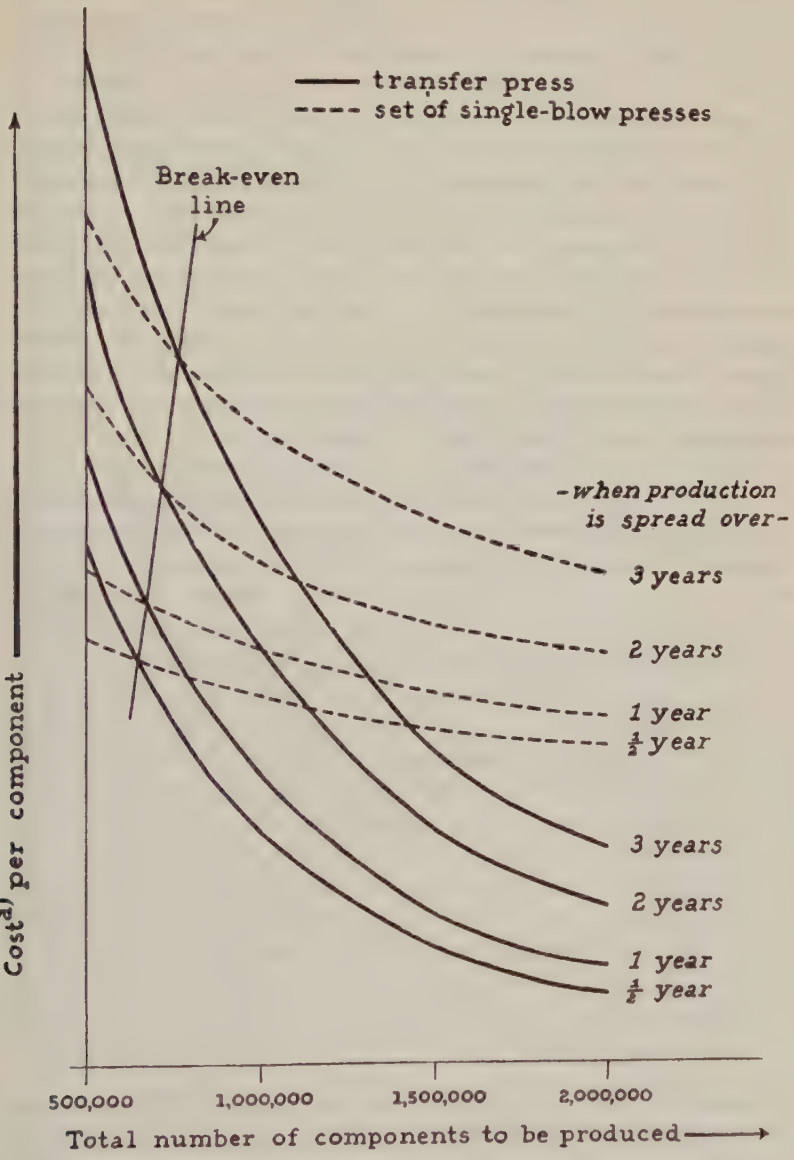


piece of components of single type varied with the number of pieces produced. This relationship was plotted for the 'old' and for the 'new' process, and separate sets of curves were drawn according as the proposed numbers of pieces were to be produced in runs of different lengths (the runs ranging from 6 months to 3 years). The intersection of the curve for the 'old' process with

Diagram III

Break-Even Points for Transfer and Single-Blow Presses

(Black's second study)



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a) *Only those costs are included which vary differently for the different methods of manufacture.*

the corresponding curve for the ‘ new ’ process indicated the break-even point for the ‘ new’—*i.e.* the minimum number of pieces of a single type which the transfer press would have to produce in a given time for it to pay (Diagram III). The analysis was still proceeding when our visits stopped. The inference seems to be that, as had been feared at the outset, transfer presses are difficult to justify economically unless they are moderately well utilised. However, the utilisation should not be achieved by a succession of short runs of different types of component, or tool costs become prohibitive. Thus the best use for these presses is a long run of a single type of component.

Green’s also possess a number of transfer presses, one of which was in the factory which we visited. It was installed as part of the new line mentioned on p. 143 above, and had been purchased to make a single type of component only. The firm’s chief production engineer prepared notes for us on several processes, in which he stated; ‘Although we have treated these particular items individually, it is most important to bear in mind that this layout should be, and indeed was, conceived as a complete entity. The individual developments and special items of equipment have their greatest value as part of an integrated whole and therefore the true economics cannot be assessed by examining them in isolation. This is true of any flow scheme of production. In the explanations that follow, therefore, the relation of each piece of equipment to others has been indicated. . . . This transfer press was purchased to produce . . . bulky components . . . which normally occupy a considerable amount of space. . . . Orthodox production techniques would have necessitated 5 to 6 operations on individual presses, and after the first operation we would have been faced with heavy inter-operational storage of cup-shaped components, storing fresh air in effect. We had, therefore, to consider not only the considerable area to be occupied by inter-operational storage, in the order of 3,000 sq. ft., but also the cost of the several presses necessary to perform the operations in addition to the cost of handling, stacking and storing all this work. After thorough investigation, therefore, the transfer press was recommended which performs all the operations at one stroke of the press[1] and is kept permanently set up for this component only. The result of this is that we now only have to store coils of raw material, cases are produced as required by the Assembly of which the press forms a part and . . . cases can be fed direct to the line. The cost of this press completely tooled and installed was approximately £15,000 and the tangible saving of utilising this method as against orthodox techniques has proved to be about 1d. per component. If this press had not been purchased, approximately £8,000 in any case would have had to be expended on orthodox equipment without any advantage.’

Clearly the method of costing alternative processes in this firm is less formalised, though not necessarily less detailed, than that of Black’s. In Green’s the decision to buy a transfer press was considered as an alternative to buying new single-blow presses, for the production of a component which had previously been bought out. It had, incidentally, then been diecast and not made on a press at all; but, since the component was not at the mercy of fashion, the firm had a considerable degree of control over its design and could also expect long continuous production runs. This, no doubt, was one argument for the use of a transfer press; but the choice had also been partly determined by the production engineer's ideas on 'momentum', as is implied by his remarks. Perhaps his case against the single-blow presses exaggerates their space-consuming disadvantages; and there seems to be no special reason to store many components between single-blow presses if the running cycles of these presses are reasonably well synchronised. To us, in retrospect, the most important comparison is simply that between the expenditure on direct labour of the single-blow presses and the higher initial cost of the transfer press and its tools. As a matter of history, even the use of the transfer press did not obviate the storage of components. The press had been used for rather heavier work than had been intended when it was first ordered, and as a result it had broken down occasionally.[1] The works manager had therefore been compelled to store increasing stocks of already pressed components in order to be sure of keeping the rest of the manufacturing line working. Again, the engineer's contention that the transfer press should be incorporated in the production line, and should produce one component only, is also debatable, and not all the staff were convinced by it: they thought that a case could be made for keeping such a press in a press shop. (This was also the view of one at least of the press manufacturers.) In fact, it was later decided that the press might be used to produce other components.

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[1] *Cf.* the makers’ advertisements, which claim that the transfer press produces a whole component ‘ in one working stroke ’—although one working stroke of such a press is really a number of simultaneous strokes by all the press tools incorporated in the machine.

Summing-up

Much of the discussion of automatic production has been concerned particularly with special-purpose equipment. Both Black's and Green's, it seemed, had bought their transfer presses for a particular job. But it was not long before fluctuations in demand for the products in question forced both firms to consider whether the presses could not be adapted for other uses. The machines were standing idle for much of the time, and the managements felt that resources were being wasted. They then seriously considered the question of the flexibility of the presses they had bought. Although, judging from the makers' catalogues, a fairly limited range of products is at present made on transfer presses, they could probably make a wider variety of products if only long runs were needed. But, as the firms' experience indicates, the idea of flexibility in a transfer press needs more careful definition than that of flexibility in, say, a fork-lift truck. A fork-lift truck can lift all sorts of different things without any special adaptation;

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[1] This type of situation was, we gathered, familiar to the suppliers of transfer presses. Firms, they complained, tended to buy presses too small for their requirements. In the first place they usually 'waste' the capacity of the press by insisting on using the first station for 'blanking' (v. p. 146)—which may take up half the available pressure at one stroke. Secondly, while they order their press with a particular component in mind, by the time the press arrives they have very likely decided to use it for a different job—often a heavier one. To obviate the risk of breakdowns due to overloading, the suppliers recommend ordering transfer presses of 50 per cent greater capacity then appears necessary.

a transfer press can make different sorts of things, but each different job it does involves new expenses—both of money (in buying new tools) and possibly also of time (in changing them). Thus a crude definition of the flexibility of a fork-lift truck would be a catalogue of the range of jobs it could do without any extra expenditure; the flexibility of a transfer press, on the other hand, must—since every new job involves expenditure—be defined by a catalogue of the jobs that can be done and of the fresh expenditure involved for each. Whether in fact the transfer press is used for any of these jobs will depend on a comparison of such costs with those of alternative methods of production; for jobs where only a small number of components has to be made, the costs are obviously prohibitive. This is rather less true of a line of single-blow presses, which is therefore in this particular sense more flexible. Not only can such a line be split up without much difficulty, but the tool costs are considerably lower, as are those of tool maintenance. Thus, if the expected run is to be short, it will certainly be cheaper to fit in a second component on to a line of single-blow presses than on to a transfer press.

Some of the production costs of putting an extra job on a transfer press may be ' hidden '. For example, the transfer press may at first be used, as it was at Green's, as part of a production line with the deliberate intention of avoiding storage, since storage consumes space and ties up capital in materials. Now if two jobs are to be put on the transfer press, it will in effect be used for batch production; and this will entail storage of both components, the more so if tool-changing takes a long time and discourages frequent switches from the manufacture of one component to that of the other. Again, getting the second component away from the press to its next operation will almost certainly involve more labour on handling and transport. Thus, even if the press is not being used for much of its time, it does not necessarily pay to put other components on to it. After all, when one component is being made, the tools for the other components will be idle even if the press is not.

The utilisation of the press—a debatable matter on which people in the firms held divergent views—must depend partly on the speed at which the press runs. If it runs twice as fast as the other machines in the line which it serves, and the line is running full tilt, it will be idle for half its time; moreover storage will be involved unless the machine is slowed up or made to run in short intermittent bursts. The speed of transfer presses has sometimes been claimed as one of their advantages; however, as an engineer at Black's pointed out, this idea may partly be due to a comparison (irrelevant in this context) between the labour productivity of a transfer press and that of a line of single-blow presses. As Table II shows, components come off transfer presses not very much (and not always) faster than they come off a line of single-blow presses.[1]

[1] The exception (press no. 4 in the table, which turned out about 2½ times as many components in the time) was due to the fact that this press was producing two components simultaneously where the single-blow presses had been producing only one.

TABLE II

Comparative Performance of Four Transfer Presses and the Corresponding Number of Single-Blow Presses[1]

Performance	*Transfer press no.:* (I)	(II)	(III)	(IV)[2]
Weekly production demand[3]:				
types of component[4]	5	1	3	2 at a time
number of components produced (all types)	135,000	32,000	75,000	18,000
Number of operations[5]:				
for transfer press	7	14	9	9
for set of single-blow presses on equivalent production	6	11	5	13[6]
Direct labour productivity ratio[7] of transfer press to set of single-blow presses ...	6¾:1	7:1	5¾:1	14½:1
Process productivity ratio[8] of transfer press to set of single-blow presses	1½:1	⅔:1	1⅛1	2½:1
Spare machine capcaity[9]:				
of transfer press	65%	69%	52%	95%
of set of single-blow presses on equivalent production	48%	78%	45%	94%

[1] The components in question had, before the transfer presses were installed, been produced on groups of single-blow presses (and certain special-purpose machines).

[2] This transfer press made two types of component simultaneously, whereas the corresponding single-blow presses had made them separately. This fact affects some of the comparisons.

[3] Weekly average of actual production called for over one quarter of 1956.

[4] Not all these types of component required special sets of tools. One component, for example, was manufactured both in brass and in steel; but, since machine performance differed between the two, they have been counted as different types of component.

[5] Operations performed on one ' characteristic ' type of component in each case.

[6] 4 for one type and 9 for the other.

[7] Based on the number of minutes per component (calculated on the ' standard cost ' basis of time allowed per component × average piecework performance figure) taken on each process.

[8] Based on the number of operating hours on each process for given number of components.

[9] These figures were calculated on the basis of single-shift working: they represent the proportion of the 44 hours during which the machines were not working.

Although the question of utilisation may worry firms after they have decided to install expensive new machinery, the decisions to install the transfer presses were based in both cases purely on considerations of relative costs. The range of possible decisions from which both Black's and Green's selected was in fact fairly narrow: in both cases the choice, as presented, was between a transfer press and a group of single-blow presses unlinked by any transfer mechanism. Black's had already got the appropriate single-blow presses, and for them the decision, therefore, involved a choice of whether or not to replace these; for Green's, who were starting to manufacture on their own account a component which had previously been bought out (from another firm, who had made it by diecasting), the decision was one of choosing between alternative types of new plant. In fact, the distinction between these two situations is not to clear-cut as might appear. In both cases the range of choice might conceivably have been wider: a linking device between single-blow presses or the redesign of the component for production by a quite different process (*e.g.* extrusion or diecasting) might, for instance, have been feasible. Again, in view of the insistence of some of the manufacturers on the dangers of overloading transfer presses and their suggestion that the heavy operation of 'blanking' might well be done on a separate machine, it would seem reasonable to have included this among the possibilities considered. A heavy single-blow press would be required for blanking; and the result of the comparison would depend on the ease with which this could be linked to the transfer press. Presumably the machine-minder of the transfer press could feed in the blanks if this were necessary. It is quite possible, of course, that such possibilities were considered by the engineers, although they were not brought into the detailed cost calculations.

The major items in these calculations depend, as has been seen, on the extent of utilisation of the transfer press and on the length of runs. Depreciation is an important item if the press is not highly utilised (as in the cases described). We met various assumptions about the life of transfer presses as used for depreciation calculations: they ranged from 15 to 25 years, and were apparently based on current conventions for single-blow presses. Apart from the possibility of product obsolescence, these assumptions do not seem very optimistic, and longer lives might appear plausible. But even the range encountered involves very different estimates of the contribution of depreciation to the total costs. If the press is highly utilised it is not depreciation but tool costs which dominate, as the cost of the machine itself is proportionately unimportant. There is not the same degree of arbitrariness about total costs that there is about depreciation—although such costs are likely to drift upwards in the future as the demand for toolmakers' services increases, and it is hard to predict any offsetting economy to such a drift.

The transfer press provides a linked and synchronised set of presses with no storage of components between them and with a single operator minding all of them. However, it does not necessarily produce more components per hour than previous methods, though it may save some space. It transfers components automatically between its stations—but it also transfers part of the labour apparently saved into the toolroom and back to the press manufacturer.

APPENDIX A.

Makes of transfer press, performance, and cost

TABLE A.1

Performance of Transfer Presses

Make of press	*Total pressure exerted (tons)*	*No. of stations (i.e., operations performed)*	*No. of strokes per minute*[1]
IWK	16	6—14	45—80
	32	6—14	36—65
	63	6—14	28—50
	100	6—14	20—38
	125	6—14	18—32
	160	6—14	16—26
	200	6—14	15—24
	250	6—14	14—22
	315	6—14	14—20
Benelli-Gavazzi	16	18—24	70
	30	16—20	60
	50	16—20	40
	80	12—18	35
	130	12—18	30
	200	10—16	25
Schuler	40	8—14	25—70
	80	8—12	25—50
	100	8—12	25—50
	125	8—12	25—45
	160	8—12	15—40
	300	8—12	15—30
	500	8—10	12—30
	800	8—10	12—25
	1,200	8—10	12—16
	2,250	8—10	8—12

[1] These are the ranges of rates stated in the makers' catalogue. The actual rates of working which we found were near or below the lower end of the ranges given—perhaps because the users allow some time for maintenance, etc., in calculating their actual rates.

TABLE A.2

Prices of Transfer Presses[1]

Make of press	*Total pressure (tons)*	*Price (£)*
IWK	16	8,600
	32	13,000[2]
	315	60,000
Benelli-Gavazzi	16	4,000
	30	4,500—5,000
	50	6,000
	80	7,000—8,000
	130	15,000
Schuler	40	8,000
	300	40,000—45,000

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[1] In general the cost of a transfer press depends not only on the number of stations and the total pressure exerted, but also on other features affecting the design such as length of

[Footnotes continued on following page

TABLE A.3

Prices of Tools[1]

Make of press	*Total pressure (tons)*	*Examples of tool cost (£)*
IWK … … … …	16	464 565 625 755 871
	100	1,429 2,590
	125	4,800
Schuler … … … …	40	2,600[2]

[1] These are naturally very variable. Benelli-Gavazzi quoted the following ranges: for first-station tools (' blank-and-draw '—an operation which on straight-line transfer presses takes two stations), £200 to £1,000; for other stations, £100 to £700 per station. The variation, they say, is due to the amount of material used in the tool rather than to the toolmaker's wage. The import duty on press tools is 15 per cent.

[2] Schuler's agent said that the grippers and feeler fingers accompanying the tools would probably cost more than £300, and the platen if one was required might cost from £500 to £1,000.

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stroke and distance between centres. No price lists are issued, on the ground that each transfer press is specially built to the customer's requirements. The above is a selection of specimen figures given to us by makers' agents and user firms; they represent ' doorstep prices ' and include (*a*) the cost of transport (perhaps 3 to 6 per cent of the manufacturer's price), (*b*) the 17½ per cent import duty if payable (see p. 145, n. 2), (*c*) the agent's commission (7 to 12½ per cent), and (*d*) the cost of training the customer's maintenance men and toolsetters if, as is usual, the makers run a special course in the country of origin or send their representatives over with the press.

[3] Including cost of installation.

APPENDIX B.

Comparative study by Black's on the costs of using a transfer press and a number of single-blow presses

The costs considered by the engineer were only those which would differ according as a transfer press or single-blow presses were used. These were the costs of (*a*) labour, (*b*) power, (*c*) tools, (*d*) tool maintenance, and (*e*) the machine itself (depreciation). All these were calculated as costs per component produced.

(*a*) Labour[1] cost *per component* was held not to vary whatever the number of components produced: the assumption was that machine minders and press operators could be employed elsewhere if their machines were not in use.

(*b*) Power was also regarded as a constant cost per component.

(*c*) The same set of tools is used however many components are produced (within wide limits). Thus the cost of tools per component diminishes with the number of components produced.

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[1] This included both direct labour and an estimate of indirect labour.

(*d*) Tool maintenance, for single-blow presses, was rated as a constant cost per component; for transfer presses it was held to diminish slightly with the number of components produced.

(*e*) The life of the machines (both transfer press and single-blow presses) was taken to be fifteen years,[1] whatever the number of components produced. If a given whole run of components is produced in, say, one year instead of three, it is assumed that the machine could be used for other jobs in the remaining two years; thus the cost of the machine as attributed to each component is less if the components are produced in a shorter time. If a longer run is to be produced in the same time, the machine cost for that time is spread over more components and will therefore be lower per component.

The relevant figures are given in Tables B.1 and B.2.

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[1] This is a different figure from that given for similar machines in Table I (p. 148); but such estimates tend to be rather arbitrary.

TABLE B.1

Transfer Press: Costs per Component

Cost per component (in pence) of		*when number of components to be produced with one set of tools is:*				
		100,000	500,000	1,000,000	1,500,000	2,000,000
Labour[1]		.155	.155	.155	.155	.155
Power		.024	.024	.024	.024	.024
Tools[2]		6.240	1.248	.624	.415	.312
Tool maintenance[3]		.655	.184	.126	.106	.096
		7.074	1.611	.924	.700	.587
	Time taken to produce the whole run of components					
Machine (*i.e.* depreciation):[4]	½ year	1.116	.223	.112	.074	.056
	1 year	2,232	.446	.223	.149	.112
	2 years	4.464	.893	.446	.298	.223
	3 years	6.696	1.339	.670	.446	.335
Total of above:	½ year	8.190	1.834	1.036	.774	.643
	1 year	9.306	2.057	1.147	.849	.699
	2 years	11.538	2.504	1.370	.998	.810
	3 years	13.770	2.950	1.594	1.146	.922

[1] This is calculated on a standard-cost formula, based on the expected time per component multiplied by an hourly rate adjusted to cover direct and (variable) indirect labour.

[2] *I.e.*, total cost of tools was £2,600.

[3] For any given set of tools, tool maintenance costs are assumed to be proportional to the number of components produced; and therefore these costs are constant per component. As between different sets of tools, tool maintenance costs are taken to be proportional to the original cost of the tools.

[4] *I.e.*, total cost of machine was £14,000.

TABLE B.2

Single-Blow Presses[1]*: Costs per Component*

Cost per component (in pence) of		*when number of components to be produced with one set of tools is:*				
		100,000	500,000	1,000,000	1,500,000	2,000,000
Labour[2]		1.069	1.069	1.069	1.069	1.069
Power		.043	.043	.043	.043	.043
Tools[3]		1.296	.259	.130	.086	.065
Tool maintenance		.028	.027	.027	.027	.027
		2.436	1.398	1.269	1.225	1.204
Machines (*i.e.* depreciation):[4]	*Time taken to produce the whole run of components*					
	½ year	.979	.196	.098	.066	.049
	1 year	1.961	.392	.196	.131	.098
	2 years	3.922	.784	.392	.262	.196
	3 years	5.880	1.176	.588	.392	.294
Total of above:	½ year	3.415	1.594	1.367	1.291	1.253
	1 year	4.397	1.790	1.465	1.356	1.302
	2 years	6.358	2.182	1.661	1.487	1.400
	3 years	8.316	2.574	1.857	1.617	1.498

[1] *I.e.*, 4 heavy and 3 light presses considered as alternative to transfer press of Table B.1.

[2] Calculated (as in Table B.1) for heavy and light presses separately and then combined. In fact, the same hourly rate was used for these operators as for the machine-minder in B.1. Although they, unlike the machine-minder, could control the speed of operation of their machines, they were assumed to work at a ' standard ' pace.

[3] *I.e.*, total cost of tools for both sets of presses was £540.

[4] *I.e.*, total cost of (new) machines was £1,250.

(*b*) HOBBING

For one of their components, Black's needed gear wheels of two different sizes and in fairly large quantities. They had used two methods of making these : the earlier and more labour-intensive method was by Lorenze gear-shaping machines, and the later and more automatic by what is called a vertical hobbing machine made by the American firm of Lees-Bradner.[1] With conventional gear-shapers, several blanks (in this case, pierced cylinders of metal) are mounted on a horizontal spindle; a single cutting tool then bites its way along them, and when it has cut a groove of the appropriate shape through all the blanks they revolve to a new position for the next cut—and so on until all the grooves are made and the toothed wheels are complete. A vertical hobbing machine, on the other hand, has four or more spindles mounted vertically on a continuously rotating platform. Each of these is loaded with a set of blanks as it moves slowly past the operator, and is unloaded when, after one full rotation, the blanks have been completely cut. In this case the cutting is done by a worm-wheel mounted horizontally

[1] This firm specialises in such equipment, and was making vertical hobbing machines as early as the 1930s.

(*i.e.* at right angles to the axis of the spindle), which passes along the blanks, cutting as it moves. Its action is essentially that of a worm-gear engaging a cog; here, the ridges of the wormwheel cutter move over uncompleted cogs, deepening the grooves as they go. Thus the Lees-Bradner consists, in essence, of four or more separate machines, each of which is first loaded, then moves away on its orbit working as it goes, and finally brings its completed components back to the operator for unloading. Because the machines are kept rotating in this way, the operator does not have to walk from one machine to another in order to load and unload them; and the machines are kept synchronised so that only one of them is ready for loading or unloading at a time. Clearly such a device is designed to be worked by an operator; for, although a hopper feed is available (at considerable expense), if the machine were to be 'automatic' to this extent it would not be necessary to mount the spindles on a rotating platform. The most obvious difference, from a labour-saving point of view, between this kind of machine and a press is that, since the operation takes a long time, loading and unloading (the job done by the operator) represents a smaller proportion of the whole cycle; and thus one operator can work several machines at once, providing they are synchronised. The synchronisation is achieved by mounting several machines on a rotating platform. The operator's top speed of working is obviously limited by the speed of rotation of the platform; but, although he need not load every spindle which presents itself to him, the machine does have some 'pacing' effect.

Black's already had one 6-spindle Lees-Bradner and 5 Lorenzes, on which they had been producing all the gear-wheels of both sizes which they needed, as well as a certain quantity of nuts. They now expected a 50 per cent increase in demand, and determined to reallocate their output between the machines they already had and those which they had to buy. They decided that all the big gear-wheels, all the nuts, and about a quarter of the small gear-wheels, should be produced on the existing 6-spindle Lees-Bradner, and their problem was to arrange for the most economical production of the rest of the small gear-wheels. The alternatives which they considered were (*a*) to buy 7 more Lorenzes, as no fewer than 12 such machines would be needed to produce the anticipated number of gear-wheels, or else (*b*) to buy one 4-spindle Lees-Bradner—in which case none of the Lorenzes would be needed.

An estimate of anticipated savings (Table III, i) was therefore drawn up in the standard form. The figures both for the 'old' and the 'new' method were based on the increased output which had been anticipated. Since such an output would, on the 'old' method, have required 7 additional Lorenze gear-shapers, the estimates in column (*a*) were reckoned at about 12/5 times the costs of working the 5 Lorenzes already in use—the estimates for the 'new' method being, of course, for the corresponding output if produced on a Lees-Bradner. The life of both sets of machines was taken as 20 years, and, as in Table I, the depreciation figures are based on machine cost only, excluding installation cost. That for the Lorenzes implies a capital cost of £18,000; and, since the cost of 7 new Lorenzes would have been £14,000, there was probably still reckoned to be £4,000 'unrecovered' depreciation on the 5 existing Lorenzes which (*cf.* Table I again) it was considered appropriate to include here.[1] (If so, Black's had presumably had them for twelve years.)

This estimate was drawn up in April 1954, and the 4-spindle Lees-Bradner was ordered accordingly. However, by the time the machine arrived there had been a change of plan, since—as had been the case with the transfer press to which Table I relates—the expected rise in demand had not materialised. Black's decided to reorganise production in such a way that the new Lees-Bradner should be used to produce the large gear-wheels only (leaving the older 6-spindle machine to produce all the nuts and all the small gear-wheels[2]). Some time later, in May 1957, it was decided to carry out a 'post-mortem' enquiry on the working of the new 4-spindle Lees-Bradner. The results of this are reproduced in Table III, ii.

The two halves of this table are not directly comparable, not only because of the different degree of reliability in the pairs of estimates but because these relate to different kinds of output. We can probably take it that the 1957 output was rather smaller. All in all, the saving on direct labour did not fall far short of what had been expected: since both sets of estimates were reckoned on the basis of double-shift working, the Lees-Bradner would effectively have saved about three workers in each case. It is not clear from the firm's account exactly how many Lorenzes were thought of as equivalent to the Lees-Bradner on the 1957 output: our guess from internal evidence is 8.[3] The most striking contrast between the two halves of the table lies in the figures relating to tools. Although the firm had had experience of both types of machine, they had apparently not anticipated the decisive saving in tool costs which resulted from using the Lees-Bradner. In the event this was so great, that, although the other gains were all smaller, and the losses bigger, than had been anticipated, their final net saving was better than had originally been hoped for.

This example emphasises the wide difference—amounting virtually to a difference of concept—between one kind of 'tool' and another. Cutting tools on machines such as these are very different from press tools. When we examined transfer pressing we found that, while there is a small tool maintenance cost which is incurred whenever the press is used, a single set of tools lasted for the longest production run we had to consider. But these

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[1] The implications of various conventions about the treatment of depreciation are discussed later (pp. 199–207).

[2] *i.e.*, all the small wheels it had produced before, plus what had been made on the original 5 Lorenzes which were no longer required.

[3] *i.e.*, 5 old and 3 new; the depreciation figure of £450 implies roughly £2,500 'unrecovered' on the existing 5 Lorenzes, plus £6,000 on the new ones. Allowing for the likely rise in some of the costs over the three years which elapsed between the compilation of parts (i) and (ii) of the table, such an interpretation—given a rather smaller output—seems plausible.

TABLE III

Cost Calculations Before and After Purchase of New Equipment

Cost of new Lees-Bradner 4-spindle vertical hobbing machine (including special equipment)	£26,455
Cost of tools	£1,200
Cost of installation	£150
	£27,805

Items affected by change of process	*(i) Costs per year (£) as anticipated before purchase*[1]			*(ii) Costs per year (£) as estimated after purchase*[2]		
	(*a*) *old method* (*12 Lorenzes*)	(*b*) *new method* (*1 Lees-Bradner*)	(*c*) *saving* (+ *or* −)	(*d*) *old method* (?[3] *Lorenzes*)	(*e*) *new method* (*1 Lees-Bradner*)	(*f*) *saving* (+ *or* −)
Direct labour (including wages, National Insurance, holiday pay, etc.) ...	2,582	1,265	+1,317	2,160	1,040	+1,120
Direct materials	no change			no change		
Overheads:						
Toolsetters	1,257	623	+634	1,410	700	+710
Maintenance: machine labour ...	561	673	−*112*	560	930	−*370*
materials	112	135	−*23*	120	190	−*70*
tools labour	no change			790	410	+380
materials	no change			3,160[4]	1,700[5]	+1,360
Power, etc.	496	305	+193	430	590	−*160*
Depreciation	900	1,320	−*420*	450	1,320	−*870*
All above items	5,908	4,319	+1,589	9,080	6,880	+2,200
Saving as percentage of capital cost ...	£1,589 on £26,455 = *6*%			£2,200 on £26,455 = *8*%		

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[1] Required output: 27,300 small gear-wheels.

[2] Required output: 13,500 large gear-wheels.

[3] Perhaps 8 (see text).

[4] New cutters, £2,830; cutting oils, £330.

[5] New cutters, £1,440; cutting oils, £260.

cutting tools wear out rapidly and are constantly having to be replaced: tool-setters' time is of considerable importance, and the cost of new cutters is heavy. Thus in this case tool costs are really one of the costs of running the machine; whereas in the economics of transfer presses the tools, because of their durability, play a role—at any rate for the production runs which we came across—much more akin to that of capital.

(*c*) AUTOMATIC PROCESSES IN PREPARING AND PAINTING METAL COMPONENTS

The sheet metal components made by Green's were painted by a mechanical dipping and baking process. There has been quite a trend towards automatic handling in such painting jobs in many parts of industry. In this case the components first had to be cleared of rust, and then cleaned, before they could take the paint. It is with the cleaning, and phosphating, process —which had been fairly recently mechanised—that we are primarily concerned. The previous phosphating process had involved the operators hanging the components on hooks on a frame, and then carrying them over to a tank—where they were dipped, left for a while, hoisted out, and carried to another tank; and so on through several tanks, each containing a different liquid. In the summer of 1953, this equipment was nearing the end of its life, as the tanks were corroded by the acids they contained and did not usually last more than three years or so. Green's would thus have had to buy new plant in any case, and the choice before them was whether to replace with equipment of the same type or to take the opportunity of introducing a new method.

The chief production engineer, called in to advise, clearly indicated in his report the reasons for their decision to innovate. The previous plant had been put in with the idea of a throughput of 3,000 to 5,000 components per week, but now production was expected to reach fully 10,000 and the plant was already overloaded: in fact, chemicals were being wasted ' owing to excessive dragout by operators on piecework ' (*i.e.* were being splashed on the floor). To cope with an expected further increase in demand, it was anticipated that the plant would not only have to be replaced (at a cost of £840) but also extended (at a further cost of £500). It was doubtful whether enough floor space was available to take such an extension; and in any case double-shift working might be necessary.[1] The firm were reluctant to incur this additional expense: ' it is to be noted that a good deal of premium work has already been done over the past two years and that a night shift has recently been re-instituted '. Finally, the fumes from the existing process had been damaging the roof, which would anyhow have to be repaired (estimated cost, £933): 'it would obviously be a pity to carry out this work without taking steps to prevent a recurrence.'

For these reasons it was decided to install a new type of phosphating plant capable of dealing with bigger throughputs and bigger components,[2]

[1] In fact, they had to introduce a night shift in the finishing shop in the interval before the new equipment was put in, in order to keep pace with requirements.

[2] And in fact, later on, bigger components were demanded.

and merely to patch up the old plant to keep production going until the new equipment was put in. The latter consisted in essence of a conveyor nearly 100 yards long, on to which were put the frames loaded with components. These were then carried into a tunnel containing a spray-cleaning and phosphating process, followed by spray-washing and forced-air drying. After a cooling sequence of some 15 to 20 minutes, the frames were ready for removal to the existing paint-dipping and baking mechanisms which had been installed about a year earlier). After passing through these, the frames were removal to the existing paint-dipping and baking mechanisms (which had been installed about a year earlier). After passing through this, the frames were unloaded and the 'empties' returned to the start by a simple monorail device (which the firm already had, but which had needed adapting for this purpose). Thus much of the manhandling in the department had by now been done away with. The remaining manual operations were (i) the first process, de-rusting, and (ii) and (iii) loading and unloading the frames.

The reasons given for not attempting to mechanise the de-rusting operation, in an otherwise fairly completely 'automatised' department, are of interest as being probably characteristic for many 'pockets'[1] of non-mechanisation to be found in automatic processes. They amount to saying, very sensibly, that while it would be better to eliminate the need for the operation entirely by more sweeping organisational changes, in the meantime the simplest thing to do is to retain it as a manual operation. In the words of the engineer's report,

> 'owing to the general handling arrangements in vogue at [this] factory, a considerable proportion of the work is rusty when received in [the department.] Further rusting takes place on work that may be quite clean when it arrives, due to the congestion of work. . . . The obvious solution is not to let the work get rusty; some little thought has been given to this and it is difficult to see how such rusting can be avoided until the transport and handling system . . . has improved. In view of this, it has been thought necessary to instal means of de-rusting, which, due to the fact it is a variable soak time process, must be manually operated.'

The 'normal' complement of direct workers in the shop was 25 to 30 men, although as few as 14 and as many as 38 had at times been employed. In addition, of course, there were foremen, charge-hands, shop labourers, and a shop-clerk—the wages of these being counted as one of the 'shop-overheads'. The phosphating process with which we are concerned employed, before the innovation, 7 workers (4 men operators, 1 woman operator, 1 labourer, and 1 supervisor). The firm kept data for the department as a whole, and not in general for phosphating separately; but on these data and the records kept by the chief production engineer we were able to reconstruct the details of the innovation as follows.

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[1] See pp. 132–134.

The engineer's original estimate of the cost of the automatic phosphating plant came to a little less than £9,000—of which the equipment was to cost £6,000 and the installation £2,000—the remainder being made up by a 10 per cent allowance for ' contingencies '. (In fact, this turned out to be a substantial underestimate: according to the notes prepared for us by the engineer in the course of our enquiries, the cost of the new equipment—including installation—had come to some £15,000.[1]) On the other side of the account, however, it was estimated that the new equipment would save nearly £12,000 a year in running costs—about £7,000 in chemicals, and almost £5,000 in wages (of the latter, about £3,400 was to be saved by the elimination of the night shift, and £1,600 because 3 fewer men would be needed in any case[2]). In addition various ' intangible ' savings were expected as a result of an improved quality of work (*i.e.*, fewer rejects), a smaller consumption of paint in the next stage of the process (because the chemical coating on the components would now be thinner and would therefore soak up less paint), the elimination of certain brushing operations on some of the components, a better flow of work, and the abolition of overtime.

The data we have been able to find in the firm's records which were made available to us refer to periods both before and after the introduction of the new process. They suggest that the estimates of savings made by the production engineer before the event were reasonably well confirmed in practice. The following cost comparisons relate to the six months before the installation, which took place in the summer of 1954, and to the months from October 1955 to February 1957 (by the beginning of this period the process had settled down to ' normal ' operation). It must be emphasised that our data relate to the department as a whole, and not to the phosphating process alone; so that the figures could be affected not only by the new installation but also by any changes that took place in the other two processes carried

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[1] ' Some considerable difficulty was encountered in changing over to a new layout as the new equipment had to be superimposed on to the old scheme without interfering with production at a time when all facilities were extended to their limit, *i.e.* day and night shift to hold the programme. This accounted in some measure for a rather higher project cost than would have been the case in equipping a completely open space, and by the same token no time was available for "de-snagging" separately from production.'

[2] In detail, the expected annual savings in labour cost worked out as follows (our allocation between ' direct ' and ' overhead ' labour follows the firm's usual practice):

		Direct Labour	*Overhead labour*
Elimination of one shift involving:			
4 men operators	2,000	2,350	
1 woman operator	350		
1 labourer	400		1,000
1 supervisor	600		
	£3,350		
No longer needed:			
2 men operators	1,000	1,000	
1 supervisor	600		600
	£1,600	£3,350	£1,600

on in the department (de-rusting and painting). As far as we know, however, these processes were not materially altered between 1954 and 1957, and we must assume that the only significant change in process was the installation of the new phosphating plant. But there is another difficulty which can neither be allowed for nor assumed out of existence—the change in the composition of the throughput from the first period (when an average of 8,648 components a week were going through the department) to the second (when the average was 9,558). The bearing of this is as follows.

The work saved by the new phosphating process was primarily that of handling frames (not that of hanging components on to the frames, which had equally to be done under both the new and the old process). Our figures of throughput are for components of all types; and, while we can adjust for the change in the *number* of components, we ought—if we are to make a rigorous comparison—to know details of the *types* of components that were going through the department at both periods. These details were not available; we only know that after the installation some bigger components were being put through than before. Now if the components had been larger, handling costs per component on the old process would have been higher than in fact they were (because there would have had to be more racks to be handled); so that the following estimates of savings in direct labour by the new process are almost certainly somewhat understated in Table IV. If this is taken into account, it would seem that the engineer's forecast was pretty well borne out by events.

TABLE IV

Direct Labour Costs Before and After Installation

	Old process (period Jan.–June 1954)	*New process (period Oct. 1955–Feb. 1957)*	*Actual saving*	*Anticipated saving*
Average cost (£) of direct labour in department:				
per week	315	252[1]		
per year (50 weeks)	15,750	12,600	3,150	3,350[2]

[1] The actual figure was £277; £252 is an estimate of what the cost would have been if the throughput had not increased.

[2] See p. 170, n. 2.

Similar calculations for 'overhead' (indirect) labour are given in Table V. The expectations of saving were not in fact realised (although of course it is possible that the discrepancy may have arisen because of changes elsewhere in the department). Green's had been inclined to hope that the introduction of new equipment and improved handling would save indirect labour because of the greater ease of control, but in this case they seem to have been disappointed. One would expect that automation would quite often substitute indirect costs for direct costs; and some of the unexpected extra expenditure may possibly have been on maintenance,

TABLE V

Indirect Labour Costs Before and After Installation

Average cost (£) of indirect labour in department		*Old process*	*New process*	*Actual saving (+ or—)*	*Anticipated saving*
Foremen and clerical workers:	per week ...	26	41		
	per year ...	1,300	2,050	*−750*	+600
Charge-hands:	per week ...	43	38		
	per year ...	2,150	1,900	+250	+600
Shop labourers:	per week ...	33	31		
	per year ...	1,650	1,550	+100	+400
All above:	per week ...	102	110[1]		
	per year	5,100	5,500	*−400*	+1,600[2]

[1] Actual figures are given, on the assumption that these overheads would not have varied with the throughout (contrast Table IV, n. 1). If we had made the contrary assumption, the figure for ' actual saving ' would have been *−100* and not +400.

[2] See p. 170, n. 2.

TABLE VI

Savings Calculations Before and After Purchase of New Equipment

Cost of new automatic phosphating equipment	£6,000
Cost of installation (including adaptation of existing equipment) ...	£9,000
	£15,000

Items affected by change of process	*Savings per year (£)*	
	anticipated (+ *or*)—	*actual* (+ *or* −)
Direct labour	+3,350	+3,150[1]
Direct materials (chemicals)	+7,000	+3,500 to +5,000
Overheads:		
Indirect labour (supervisors, clerical workers, shop labourers)	+1,600	0 to *−400*
' Consumables ' (miscellaneous materials used in the shop)	0	+400
Power, etc.	0	*−50?*
Depreciation[2]	*−750* to *−2,460*	*−1,600* to *−4,460*
All above items	+9,490 to +11,200	+2,190 to +6,900
Savings as percentage of capital cost	63% to 75%[3]	15% to 46%

[1] Adjusted for changes in throughput (see Table IV, n. 1).

[2] Our estimates. The depreciation calculations are based on the following assumptions: (*a*) that the new equipment will last from 3 to 7 years; (*b*) that the old type of equipment, which Green's would have had to install and extend if they had not bought the new (see p. 57), would have lasted 3 years; and (*c*) that the roof of the shop, which would apparently have had to be repaired regularly if they had in fact continued with equipment of the old type, would have lasted 10 years. The calculations are fairly similar to those of Black's. (see pp. 147–148); their implications are discussed in more detail on (Section IVe).

[3] On the capital cost as originally anticipated (£9,000), these percentages would be 102 to 124.

The most important of the anticipated savings—even more important than on all types of labour, direct and indirect—was on chemicals: Green's hoped to save nearly £7,000 a year on this item.[1] It is difficult to find out exactly what happened, since the records were more scanty and hard to interpret. The only data we found related to one chemical only—albeit an important one, on which a saving of £2,300 a year had been hoped for. In fact, it seemed that only £1,300 was actually saved. *If* the actual saving on the other chemicals bore the same relation to the predicted saving, then the total saving on chemicals would have been about £3,700.

There is a miscellaneous set of items used in the phosphating process which are known as 'consumables'. No saving had been anticipated on these, but in fact it appears from the records that about £400 a year (again after adjusting the figures appropriately to the new throughput) was saved.

We may summarise (Table VI) Green's experience in carrying out this installation. The contrast between the two methods is so strong that one does not have to worry about fine points in the cost calculations. The saving, both of direct labour and of chemicals, was so marked that, even though the capital cost was much bigger than had been budgeted for, granted that the new equipment had a reasonably long useful life it certainly proved worth while. One might indeed speculate why the change had not been undertaken earlier. But the original plant, primitive as it was, had been put together when the throughput was still comparatively small and the firm was not at all sure that demand would increase. In fact, it increased rapidly, and it was then that the innovation became worth while. Even so, it was considered only when the old tanks were having to be replaced anyway; perhaps it would not in any case have been put on the agenda till then. Since however the life of the tanks was fairly short, there was probably not overmuch delay.

The effect of the innovation was to save some direct labour[2] and a good deal of material. How far the latter economy actually saved labour at the chemical plant from which Green's got their supplies, or at some earlier stage, it is impossible to say; at Green's, a little more was spent on indirect labour—perhaps maintenance.

(*d*) Machine Moulding in Iron Foundries

The essential of a foundry is to make cast metal components, by pouring molten metal into moulds of the appropriate shape and letting it solidify. The first stage, which is usually undertaken outside the foundry in a separate shop or factory, is to make a master pattern of wood, and a working pattern of metal, in the shape of the required component. A mould is then formed round the pattern, generally in parts so that the latter can be removed from it. The mould is made—usually in a large box—of a mixture of sand and bonding material, and is compressed firmly to receive the molten metal where the pattern had been, so that the metal takes up just that shape. If the required component is hollow, a core—also of bonded sand—has to be made for the inside of the component. The core is usually baked for some time—perhaps as much as an hour and a half—to make it specially hard,[1] although this time can be reduced to almost nothing if the core is ' cured ' (treated with resin). Of course, holes and channels have to be made in the mould so that the metal can be poured in—which means that the casting will, when it is taken out, have extra metal (' runners ' and ' risers ') attached which need to be removed later together with the burnt sand adhering to the casting (this finishing process is known as fettling). Once the metal is cast, the mould must be broken up; the pattern, of course, is used very many times. Because metal contracts when it cools, the pattern will have been made a little larger than the required component.

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[1] The new process was to require considerably smaller quantities, although the chemicals would be rather more expensive.

[2] Though not, we gathered, quite as much as had been hoped—partly owing to trade union resistance.

The process is a traditional one, and still survives in places in its pre-mechanised state. The work, particularly in old-fashioned foundries, is hot and hard: moulds of any size are made on the floor, and the molten metal has to be carried over to them. The skilled part of floor moulding consists of pressing the sand mixture firmly round the pattern (by stamping it down, and especially by ramming it with a metal rod), and of making the right sort of channels for the molten metal to flow in without turbulence and bubbles; the actual pouring in of the metal is a comparatively unskilled job, although it requires care.

In one type of mechanised foundry, the sand, instead of being packed round the pattern with boot and rammer, is blown forcibly from a nozzle or ' slinger '—which may, however, be guided by hand. After the removal of the pattern, which is taken automatically back to the start of the process, and the insertion of the core, the boxes containing the moulds are taken past the furnace where the molten metal is poured in. The line then continues to the cooling and fettling processes. In another form of mechanised moulding, the sand is dropped in and then compressed by a ' jolt-squeeze ' machine (which does exactly what its name implies). With either of these moulding processes a very high degree of mechanisation is possible in the handling of the boxes, the moulds, the castings, and the sand.

Some very advanced foundries are now in operation (see the recent publicity for Ford's).[2] Our firm, Brown's, which used small ' jolt-squeeze ' machines, had a much less advanced type of mechanisation, because it is a small firm which specialises in short runs.[3] To give our study perspective, however, we also visited Silver's—a firm which has two large modern foundries with up-to-date practices. In all these foundries a certain amount of floor moulding was carried on[1]—the more primitive process being retained for very short-run or ' one-off ' requirements which it was not worth putting on to the production line, including the making of metal patterns[2] from wooden patterns (which required special attention). In Brown's—as, no doubt, elsewhere—floor moulding was also retained for quantity production of components which were too large for their moulds to fit into the standard boxes.

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[1] While the mould has to remain porous so that the hot gases can pass through it, this is unnecessary with the core.

[2] *E.g.* in the Finance and Industry Section of the *Manchester Guardian*, May 29th, 1958.

[3] They were also anxious to avoid one very heavy cost associated with highly mechanised moulding, namely that of ' revivifying ' all the sand used. ' Facing sand ' (*i.e.* that which is adjacent to the casting) is chemically changed by the molten metal, so that if it is to be re-used as facing sand it has to undergo treatment in order to restore it to its former condition; alternatively, it has to be thrown away. The ' backing sand ', however (*i.e.* that which does not come into contact with the casting), needs no treatment. Where the handling of sand is highly mechanised, it is impossible to make separate applications of facing sand and backing sand, so that the whole of the sand used has to be restored to ' facing ' quality. Brown's however, were able to apply the necessary quantity of facing sand first, and to use the backing sand over and over again without treatment

In one of Silver's foundries, the moulding operation was accelerated by an arrangement to feed the slinger with moulding boxes as fast as it could fill them; in the other, the jolt-squeeze machine itself worked very fast. Because of its speed, machine moulding lends itself to incorporation in an integrated line, which involves mechanical handling between processes in order to achieve a smooth flow of components. At Silver's this was done by a variety of handling devices—cranes, overhead conveyors, and sets of rollers. Brown's, however, had not hitherto found it economic to exploit the speed of their small jolt-squeeze machines fully. The boxes were lifted by small electric cranes, but placed in position and filled by hand. The formation of the mould was quick, but the box remained on the machine until the men removed it.

In fact, neither speed of operation nor a lowering of costs were Brown's main or only objectives in introducing mechanical moulding, although they seem to have found afterwards that they had in fact achieved both. They had, however, a general feeling that the foundry needed bringing ' up to date ', and that it was advisable to make themselves less dependent on the availability of skilled floor moulders as the flow of recruits seemed to be drying up. The proposal to introduce machine moulding met with little or no resistance from the men, partly because they did not believe Brown's would succeed.

Neither the firm nor ourselves were able to estimate what happened to their money costs at all exactly. They made a mix of products, both by floor and machine moulding methods. In each case a different type of product might be expected to involve a different amount of work. For example, a complicated shape is more difficult to make and requires more care than a simple shape of the same size and weight; and a large component is likely to need more work than a small one, especially in floor moulding. Thus any product mix will give rise to difficult accounting problems if the firm thinks it worth while to tackle them. Brown's did not: they liked to cut paper work to a minimum, had acquired some confidence in their intuitions, and were selling in the special non-competitive market conditions described earlier. Also, to achieve greater flexibility, they had a policy of building up a reserve of machines for future expansion, to some extent regardless of what they were producing at the moment. This meant that their purposes were probably well served by 'losing' their machine purchases in factory overheads; for detailed allocations of overheads tend to relate particular expenditures to specific needs arising out of current production.

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[1] Silver's planned to continue this practice: the floor moulder had a young apprentice.

[2] Metal patterns, because of their durability, are essential for machine moulding, and where long runs are needed.

We had had some hope of assessing such money economies as were made by the innovation by looking at costing figures compiled after the event, when both moulding processes (hand ramming and mechanical jolt-squeezing) were being operated side by side. In fact only two relevant sets of figures proved to be available, neither of which gave a clear-cut comparison. The first (Table VII) compared the costs of what were almost certainly different kinds of output in a particular specimen week; the second (Table VIII) compared the costs of the same kind of output at different periods. The main assumptions underlying Table VII are (*a*) that foundry output can be adequately measured by weight, and that the costs of floor and machine moulding can be compared on this basis alone, and (*b*) that the cost of direct labour (*i.e.* moulders' and coremakers' wages) is the only cost that varies between the two processes. (*b*) may well be a valid rule of thumb; but (*a*) clearly does not

TABLE VII

Average Cost of Castings for 1947[1] and for a Single Week in 1956

Item	*1947 (whole year*		*1956 specimen week)*			
	floor moulding: cost per cwt.	*%*	*floor moulding: cost per cwt.*	*%*	*machine moulding: cost per cwt.*	*%*
Direct labour	14/3	43	17/6	37	11/–	27
Direct materials	6/7	20	13/2	28	13/2	33
Indirect labour	10/–	30	11/8	25	11/8	29
Indirect materials (including fuel and power)	2/3	7	4/7	10	4/7	11
Total of above	33/1	100	46/11	100	40/5	100

[1] The year before the installation of machine moulding.

TABLE VIII

Comparison[1] of Moulding Costs for Particular Components

Component		*Cost to mould floor*	*Cost to mould machine*
Type A:	bottom	11/3	7/6
	middle	16/6	12/–
	lid	11/3	8/–
Type B:	door	5/11	4/6
	side	6/10	4/6
	top	11/–	8/–
	flap	1/7	1/3

[1] The figures for machine moulding refer to a date four or five years later than do those for floor moulding.

hold except where castings are all of the same general type. It is not only that Brown's are, on the whole, now making lighter but rather more complex (and therefore rather more expensive)[1] castings than they used to; even in the short term, the differences in cost for castings of the same weight and produced by the same process are considerable. Thus, in the specimen week to which Table VII refers, average direct labour costs per cwt. of castings were 11s. for machine as against 17s. 6d. for floor moulding; but we were told that in one week in the following year the corresponding figures were 13s. 5d. and 40s.: a very different relationship. These wide variations in cost per unit of output reflect—naturally enough in a batch-producing firm[2]—a widely varying product mix. Not only are very different products turned out by floor moulding as well as by machine moulding, but the proportion of total output which is turned out by each process is also likely to fluctuate to some extent. We gathered that the great bulk of Brown's castings were now being produced by machine moulding: in the single week in 1957, the machine output was 10 to 15 times as great as that from the floor, but the firm could not be much more precise than this.

Table VII consists of estimates, prepared for us by Brown's accountant, of the cost of direct labour for the same components produced by the two methods (by floor moulding before the installation was made, and by machine moulding afterwards). Again the comparison is imprecise; the actual dates to which the two sets of figures refer were not clear, and no allowance could therefore be made for any increase in foundry wages in the interval.

Table IX, which is set out in the same sort of form as that used by Black's, indicates—on the basis of the direct labour costs for floor and machine moulding in the one week of 1956 for which we have details—the savings that would have been made if these costs had obtained for the whole year (and if floor moulding had been completely displaced). We know that they did not; but the table may nevertheless give some idea of general orders of magnitude.[3] At any rate, in this week of 1956 Brown's saved about 6s. 6d. in direct labour on every cwt. of castings they produced by machine moulding instead of on the floor; in the specimen week of 1957, the corresponding saving was over 25s. The only charges to offset this gain were the cost of the machine (*i.e.* depreciation) and of the power needed to run it—which together amounted to less than 1s. 6d. in both cases.

Perhaps a better indication of the sort of savings that were in fact made can be obtained from the data for the specimen week of 1957 mentioned

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[1] Silver's went so far as to say that the cost of castings was ' the cost of the holes and not the cost of the metal '.

[2] Even if Brown's had fairly long runs in prospect, they preferred on grounds of flexibility to produce in batches of, say, 50 components at a time. They could then interrupt a run if need be for urgent orders or for special modifications if these were called for.

[3] If the figures for the specimen week of 1956 were representative, these savings would be overestimated for two reasons: (*a*) because, as is explained in note 2 to the table, some small part of the output was still being produced by floor moulding, and (*b*) because the particular jobs that were in fact reserved for floor moulding would probably have been more expensive had they been able to be put on to the machines, than the jobs which were in fact produced in this way.

TABLE IX

Cost Calculations on the Basis of a Specimen Week in 1956[1]

Cost of 7 new moulding machines	£10,500
Cost of installation and special equipment	£ 3,000 approx.
	£13,500

Items affected by change in process	*Estimated cost per year (£) of producing total output*[2]—		
	—by old method (floor moulding)	*—by new method (machine moulding)*	*saving* (+ *or* −)
Direct labour (moulders and coremakers) ...	27,930	17,556	+10,374
Overheads:			
Power, etc.	—	634	*−634*
Depreciation[3]	—	1,350	*−1,350*
All above items	27,930	19,540	+8,390

Note. The above estimates are subject to very wide error margins, not only because of the assumption that costs of castings are directly related to their weight but also because the only week for which figures were available was admittedly unrepresentative of the year as a whole.

[1] The week referred to in Table VII, when the cost of direct labour per cwt. of castings was 17/6*d.* by floor moulding and 11*s.* by machine.

[2] 1,596 tons. The total direct labour cost for the year was £24,244. On these figures, the above costs per cwt. for floor and machine moulding would imply that little over a third of the total output was produced by machine, but we know that the proportion was in fact much higher than this. In the circumstances, and since we have no record of the tonnage produced by each method, it seems simplest to compare the costs of the total output as produced by each—although, since a small part of the output was in fact still being produced on the floor, the estimated saving is somewhat overstated on these assumptions.

[3] Brown's policy is to write off their machines, using the ' straight-line ' method, over 10 years. In this case they consulted the suppliers of their new equipment about its probable life, but saw no reason to depart from their usual practice.

above. For this week we were given not only the direct labour cost on each process (40s. per cwt. on floor moulding and 13s. 5d. on machine moulding), but were also informed that the quantities produced by the two methods were 38½ cwt. and 560 cwt. respectively. These latter figures suggest that the week was more typical of the normal run of Brown's production than was the specimen week in 1956 on which Tables VII and IX are based; for the weighted average direct labour cost of the combined output in the specimen week of 1957 comes to about 15s. 3d. per cwt., which compares tolerably well with the corresponding average for the whole year of 15s. 11d. If however the calculations carried out for Table IX are repeated, using the costs of the 1957 specimen week and the total output for the year of 1,422 tons, it would apparently have cost £57,000 in direct labour to produce the whole output by floor moulding, and only £19,000 to have produced it by machine moulding; and so gigantic a saving as £38,000 in one year on an investment of about £13,000 is hardly plausible.

The trouble with the calculation is that 40s. is the cost per cwt. of producing by floor moulding the kind of things which are still produced in that way when the foundry is organised to produce the great bulk of its output by machine moulding. If the foundry were organised to produce its whole output by floor moulding, the direct labour cost per cwt. of castings would certainly not be as high as 40s. Probably a better way of arriving at an estimate of the cost of floor moulding is to take the cost at the time when the foundry was in fact producing everything in this way, and to inflate that figure by the rise in moulders' wages which has taken place since that date. In 1947 (an appropriate date) the direct labour cost per cwt. of castings was about 14s. Since loose-pattern moulders' earnings have risen by something like 75 per cent in the ten years since then, 25s. per cwt. would seem to be a reasonable estimate of the direct labour cost of floor moulding in 1957, if the foundry as a whole were still geared to producing by that method alone. At that rate, the total direct labour cost of the 1957 output would be £36,000, as compared with the £19,000 to produce it by machine moulding. On this estimate, then, the saving amounted to some £17,000—which, on an investment of £13,000, may be considered a very good return for the firm.

It is not really possible to say more, since Brown's records were so limited that to attempt further refinements would be to strive for spurious accuracy. The practice of costing output by weight, fair enough in the nineteenth century when castings were less elaborate and costing was embryonic, is often regarded—by Silver's for instance—as seriously misleading and quite obsolete in the light of modern foundry technique and accounting practice.[1] Similarly, some firms would dispute the wisdom of relegating the depreciation on a particular piece of equipment to general factory overheads instead of charging it to the process in question. To Brown's, however, the advantages of machine moulding were too self-evident to warrant spending time on keeping records or on making detailed calculations to justify their decision after the event. After all, the method has been extensively used elsewhere at the time: they were adapting a well-tried technique to rather different conditions. Nevertheless, this is an example of a way in which technical development gains ground. They had originally experimented with machine moulding in a small way,[2] not so much because of its immediate profitability as because they wanted to ' move with the times ' and to escape being dependent on a dwindling supply of labour. But it must always have been clear to them that their main expense in the foundry was the cost of direct labour, and that if they could succeed in reducing the number of moulders and coremakers the installation would prove sound enough economically (though they were apparently surprised at the degree of success they achieved). By comparison, the question of product mix was secondary, and they no doubt decided that it could safely be ignored. There were in fact about 100 direct foundry workers at Brown's just before the war; by 1948 (shortly after the introduction of machine moulding) there were 60, and by 1957 only 38. Indirect labour in the foundry fell in much the same proportions. Employment had thus been reduced by nearly two-thirds; in the same period, the tonnage produced had fallen by perhaps one-third—a drop which, in view of the trend towards lighter castings, probably means little in any case. As for the allocation of depreciation, Brown's could doubtless have drawn up an estimate of savings on the lines of Table IX if they had thought it worth while. They did not: their attitude was that, since the foundry served the factory only and none of their castings were sold outside the firm, they preferred to treat the castings as—in effect—raw material for their final products. Depreciation charges, like administration costs, were treated as factory expenses, and were allocated as factory overheads to their final products at a later accounting stage.

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[1] ' The cost of a particular " mix " of metal poured is computed in pounds per ton or in shillings per cwt. and is taken at the average price for each " mix " irrespective of how it is used. With moulding and coremaking, however, this average method is not practicable. The cost of each specific job must be ascertained since each one is likely to differ from all others. . . . Where the Moulding Department comprises different sections using different methods of moulding, *viz.*, Floor Moulding, Machine Moulding, etc., each of these sections should be regarded as a separate " department " for costing purposes. The costs may differ considerably as between these different sections. This division must be remembered when analysing direct labour and in the allocation and apportionment of indirect wages, materials and expenses.' (H.P. Court and W. E. Harrison, *The Elements of Foundry Costing*, Council of Ironfoundry Associations, 1956, pp. 12, 13). However, the convention of costing castings by weight was no doubt less misleading at Brown's than it would have been at Silver's, for Silver's were making a much wider, more varied, and more complex range of castings.

[2] They were proud of having gone ahead in the face of doubts from the suppliers of their moulding machines, who thought Brown's were proposing to use them for making bigger moulds than they could satisfactorily produce.

While we examined quite a number of other processes in the course of our visits, we are confining ourselves to describing the above four. We chose these because the processes are very diverse from a technical point of view but are each typical of engineering practice. Their introduction and operation raise a number of general questions for discussion in the following section.

C. SOME ECONOMIC QUESTIONS INVOLVED

(*a*) Labour Saving and Productivity

Every study assumes, of course, a standpoint and a field of reference. The spate of studies on automation—at any rate, those incorporating the word in their titles—imply a hidden balance sheet difficult to draw up with any show of precision, set out in terms primarily of the *labour* involved in alternative ' old ' and ' new ' processes. They are, therefore, partial studies, for they ignore other resources which are also used in manufacturing processes: energy, for example, or the space utilised, or already existing machines, or the mineral resources of the earth. This predilection for accounting in terms of labour arises for one of two opposite reasons: either people think that the amount of labour available is likely to prove inadequate for achieving some productive end, or they fear that it will be unemployed. This symmetry (prospective scarcity, prospective glut) would not appear if the accounting were done in terms of the other economic resources. But, since most western economies have experienced both kinds of situation within a single generation —the ' overfull ' employment of the war and post-war years, and the mass unemployment of the inter-war depressions—it is not surprising that people's attitudes to the introduction of automatic processes are coloured in this way.

In particular, the literature of automation has tended to inflate people's anticipations both of glut and of technological unemployment in the not-so-distant future. Thus the descriptions of the 'fully automatic factory' are apt to arouse, in the individual factory worker, a picture of himself becalmed, like the Ancient Mariner, in a sea of manufactured goods without the income to buy them. The expectation of sudden glut implies that of a sudden increase in the productivity of the community as a whole. But one or two automatic factories do not make an automatic world. If we confined ourselves to small enough units of the productive processes of the economy, we could for a long time have found 'fully automatic' machines, processes, and even departments: machine shops full of automatic lathes, paint shops spraying and drying paint, and shops where screws or pins, pistons, oil or confectionery are produced or processed. The automatic machine, the automatic process, the automatic department, and the automatic factory are recognisable stages in the development of industry—although the lines of demarcation between machine, process, department and factory may not be particularly relevant if we are thinking of the productive process as a whole. For some industries the ascent has been easier than for others, and such industries have long been high on the ladder. We take them for granted; what excites us is when industries take a step up.

Moreover, from a labour productivity point of view, the automaticity may be something of an illusion: it often has to be tended by many hands. The maintenance men make their rounds; the tools on the lathes wear out, and are replaced from the toolroom, where the toolmakers have been making them—engaged just as surely on the process as the machine operators of yesterday.[1] Moreover, if we do our accounting over sufficient time, we must observe that the automatic machines themselves usually have to be replaced; so that we should count the makers of machine tools as contributors to the process too. This means that the types of accounting in the short run and the long run are different. In the short run, one would generally do one's accounting in terms both of existing machines and of current labour; but since future machines will have to have labour expended on their manufacture as well as on their operation and maintenance, any long-run accounting will be increasingly dominated by labour. True, the labour will have been expended at different times, and to aggregate it in this way is useful only for long-run assessments. But such assessments are essential for considering the long-term trends resulting from technological change. There appears to be a clear tendency for the labour productivity of the country as a whole to rise: for a decade after the second world war, the gross national product per head increased by about 2½ per cent per year, although the rate of increase has not been constant. Only a part of the rise can be ascribed to the more spectacular examples of technological change such as electronic control mechanisms: a part, and probably a large part, can be explained by far more prosaic devices, and also by better ' housekeeping ' in the factories.

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[1] The point, important to us today, was grasped by some during the dramatic upheavals of the 'first' industrial revolution: 'There are a great number of persons employed about the power loom in various preparations of the article before it comes into the loom, and so many mechanics are employed in making the machinery and keeping it in order, that I do not imagine from what I have understood, that more than one-third to one-fourth is saved by the use of the power loom.' (*Commons Committee on Emigration, 1826–27, Evidence,* p. 181).

Technological change may certainly result directly in unemployment if the displaced labour is very specialised; but unemployment may also develop indirectly, through the failure of effective demand to keep pace with the rise in productivity. As regards the first, it is characteristic of changing techniques that many different kinds of machines (and semi-processed materials) are called for: that is, different kinds of ' indirect ' labour are required, possibly from quite different parts of the world. Such transfers of the call for labour may easily lead to the appearance of patches of technological unemployment in particular countries, districts, or factories: the ability to transfer work has, as its obverse, the power to transfer unemployment. In a mechanical age, fluctuations in employment can be magnified in machine-producing countries, either because orders are postponed or because they are placed elsewhere.[1] This is a serious problem: but it is hardly new to the second half of the twentieth century.

The other aspect of the unemployment problem is that of keeping effective demand (*i.e.* demand which has the money to back it) in step with the productive potential of the community. These interact on each other to some extent, and indeed cannot quite be defined independently: an increase in effective demand may stimulate an increase in productivity, either by achieving a high utilisation of existing machinery, equipment, or labour (see pp. 186-192) or by making possible the use of different methods of production which, at the previous level of demand, were uneconomic.[2] Conversely, an increase in productivity may raise effective demand through lower prices or higher real wages. But the interaction of the two is by no means assured, and each tends to be the province of a different set of people. Productivity is the realm of the business man, who is apt to think that the maintenance of effective demand is a rule of the universe and its failure an Act of God; while effective demand is the field of the economist, who has sometimes appeared to treat productivity as a parameter of the system.

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[1] For example, much of the automatic machinery for making motor-car engines and bodies now comes from Germany or America, so that the work of making British motors has in this sense partly been transferred to these countries. (This is possibly due in part to the conservatism of British machine-tool manufacturers; another aspect of this is discussed on p. 198). Had it not been for the almost continuous increase in demand for this particular product, patches of technological unemployment might well have appeared here.

[2] Both these cases of ' economies of scale ' were exemplified in our case studies. The second was illustrated by the substitution of a transfer press for a set of single-blow presses, and the first by the lowering of the cost per component to be achieved by higher utilisation of equipment.

While we cannot be sure that the twin problems of unemployment have been solved, it seems reasonable at this time, and in a study of this kind, to lay much greater emphasis on the problems of raising productivity rather than on those of keeping it down so as to maintain employment.

One of the firms with which we were concerned, Black's, was particularly interested in increasing its production to cope with an expected steady rise in demand. It wanted to do this without expanding its labour force, and so it had to concentrate on raising its labour productivity—by continuously re-equipping its factories with the most modern 'labour-saving' plant it could find. This included transfer machinery of all kinds—not only machines designed as complete units, like transfer presses, but also linked machines, partially automatic assembly lines, and fully automatic finishing processes of many types. The firm had in fact succeeded in increasing its production while keeping its own labour force constant; but against this must be set a possible increase in the labour of those outside the firm (and in some cases outside the country) who made, sold, and transported some of the large and intricate machinery. A rise in productivity for the community as a whole obviously means a saving somewhere along the line: it may be, for example, that machines become cheaper or more reliable, or it may be simply that those who use them use them better. From the community's point of view, a firm's decisions to innovate cannot be measured purely by their effect on the productivity of the firm's own labour; its decisions may also either reduce or increase its call on resources outside.

Black's earlier strong emphasis on its 'own' labour productivity, though still—justifiably—surviving up to a point, had fairly recently given way to a more comprehensive type of accounting in money terms whenever a new process was being considered. Such accounting must necessarily be coloured by conventions, but (if these are not too misleading) a large proportion of the money cost of a new machine, and of the raw materials which it processes, must ultimately have gone to pay the wages of those concerned directly and indirectly with their production, sale, and transport. Thus, by and large, if such an accounting procedure anticipates a new saving, or rather if a saving is in fact achieved in practice, we are fairly safe in assuming that the process in question is resulting in higher productivity from labour in general (and not merely from the labour of the firm in particular). For the firm to have thought solely in terms of its 'own' labour productivity might have resulted in its using a proportion of outside labour high enough to make the change responsible for a decrease in labour productivity if the accounting were done for the community as a whole. Even so, the decision to innovate might be understandable from the firm's point of view, supposing it were badly placed for attracting more labour.

This sort of situation—of a prospective shortage of a particular type of worker—confronted Brown's when they decided to install machine moulding in their foundry. They took this decision without any formal costing, but, by good luck or good judgment, their costs (and therefore by implication their call on labour generally) were heavily reduced. However, the pressure on them was such that, even if their costs had increased, they would have been forced to innovate. We have seen that they were inclined to build up a stock of machines even if there was no immediate prospect of using them. One can accept this use of the community's labour resources only if one also accepts the firm's judgment that there may be an emergency and that the machines now unused would prove useful in it.

While Brown's decisions were not based on detailed cost considerations, Green's (like Brown's) were certainly concerned ultimately to reduce costs. Their emphasis, however, was very different from Black's: they tended to concentrate successively on some particular aspects of operations which they thought were indicators of waste and inefficiency. For example, one process was designed to keep up productive ' momentum '; the emphasis here was to reduce stocks and to save space (space, in fact, was given great importance in the production engineer's thinking). An emphasis on the economy of space ostensibly implies a saving of community's resources of land rather than of labour; but in fact labour is involved in several ways. Thus a saving of space can mean a saving of new building; indeed, if the saving is one of not adding an extra floor to an existing building, labour alone is involved. A more compact process may be easier to supervise and may necessitate less waste of time in walking about. As a matter of fact, Green's were concerned with the waste involved in walking about, and in the notes produced by their production engineer to justify one of their innovations they based their case on the following figures:

	Per day	*Per year*
Saving in distances moved:	16,960 ft.	4,070,400 ft.
I.e. Saving in labour at 3s. 1d. per hour:	£6 10s. 3d.	£1,563

Green's also drew up a detailed account of their factory overheads, and concerned themselves with ways of keeping them down—though again rather as a separate exercise. This fragmented approach to costs was thus sometimes carried out in terms of space, sometimes in terms of direct labour, and sometimes with one of the overheads in mind. The production engineer concentrated on looking for the main bottlenecks or obstructions in his processes, and therefore for ' natural ' improvements. Whether or not the result increased labour productivity in general depends on how far these ' obvious ' improvements were offset by the hidden costs which are too often associated with any change.

In fact, each firm had a different ' philosophy of production '—*i.e.* tended to concentrate on different aspects of the productive process. We are not attributing permanence to any of these ' philosophies ', which by now may well have changed in emphasis: indeed, our account of them may seem to have an element of caricature about it. Nevertheless, it seemed necessary to attempt some classification along these lines, as we felt that the economic data alone told only a small part of the story. The ' production philosophies ' of firms arise partly out of their economic environment, but they also arise partly from the personalities, relationships, and previous experiences of their managers. Thus in Black's, situated in an area where the competition for labour is intense and the demand for their products always liable to rise, the prevailing tendency was towards continual mechanisation and (in view of the high cost of new machinery) high utilisation; in Green's, where quite a large measure of handworking—even though this was machine-assisted—was retained on some production lines, the insistence on ' keeping up momentum ' (essentially a policy of avoiding ' banks ' of half-finished components) was primarily intended to keep people working quickly. The idea of ' momentum', however, was also carried over to more fully mechanised lines where its rationale is quite different: in such cases its principal virtue is its avoidance of having to put components down and take them up, which often amounts to installing a further and more expensive process.[1] The emphasis on space saving in Green's seemed odd in the context of the particular factory we visited, since its site was spacious; although, since Green's were also looking forward to expanding production, space saving amounted to a postponement of factory extension and rebuilding. However, detailed accounting would be needed to see whether their policy was really justified. It is clear that the sort of ' production philosophies ' held by firms must affect their attitudes to innovation and, in particular, must determine the kind of ' labour saving ' at which explicitly or implicitly they aim.[2]

At any rate we can see that labour saving in the general sense is a more complicated concept than is usually assumed. If by labour saving we mean the raising of the labour productivity of the community in general, then—in so far as this can be achieved by purchasing new machinery—its achievement must depend not only on how much ' direct ' and ' indirect ' labour is saved by the new machinery in the firm which installs it, but also on the intensity and frequency of the calls on outside labour[3] (*e.g.* on how often the machine is replaced). We have assumed, as a simplification necessary to make an important point, that a new machine represents indirect labour in the process on which the machine is used, just as surely as do the engineers (maintenance men, toolsetters, etc.) who are required to keep it working. This is, of course, only one standpoint from which a machine can be viewed in its economic context. Admittedly, to an economist a machine is a piece of capital; but the word has no sharp meaning.[1] In concentrating on the indirect labour aspect, we have been neglecting one of the distinctive aspects of capital, *i.e.* the gap in time between the making of a machine and its use. In an uncertain world, a machine may have to be used for a different volume of output—or even for a different purpose—from that for which it was ordered. After a machine has been made, it becomes (like the land it stands on) part of the economic landscape—*i.e.* part of the context in which decisions have to be made. It is mainly because the original decisions—reasonable enough when they were made—may later have to be modified, that the usefulness and the value of a machine alter as time goes on. The types of decision which can be made after the machine has been installed relate to the extent of its utilisation, its flexibility (*i.e.* its potential alternative uses), and its replacement.[2]

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[1] *Cf. Keeping Pace with Automation* (Report of Conference of American Management Association), 1955, p. 30.

[2] Any large-scale survey of innovation would, we feel, have to include data of this kind.

[3] The cost of labour outside the firm is, roughly, represented by the cost of the new machine, the cost of the power to run it, and the cost of the materials it uses. If, as is usual, these costs are to be assessed on an annual basis, then we have to assume that the firm is using a plausible method of calculating depreciation—since the total ' cost of the new machine ' is divided into annual portions according to the prevailing convention. (Such depreciation conventions are discussed on pp. 199–207 below).

(*b*) UTILISATION

The pressure for high utilisation of large pieces of equipment is of great importance in industrial practice. Both Black's and Green's were concerned with the problem, and conflicting views were expressed at different times even in the same firm. Black's in particular had done a very revealing study, stimulated by the low utilisation of their transfer presses,[3] which showed a steadily developing insight into the subject.

Undoubtedly, many people in management feel annoyed when they see large pieces of equipment lying idle in their factory. To them the machines represent ' capital ' and they feel that capital is something on which it is their job to get a good return. Idle plant is idle capital and is ' not earning its keep '. Such is their intuitive view; to recall the dictum of one of the engineers in Black's, ' low utilisation pinpoints inefficiency '.

On the other hand, one hears the alternative view that if a machine fulfils the purpose—that is, achieves the rate of output for which it was installed—more economically than the machine it replaces, then the state of affairs is satisfactory even though the machine may lie idle for some of the time. There is clearly something in both arguments; can the dilemma be resolved?

(i) The first useful definition of utilisation is the actual rate of output of a machine over a given period (say a month or a year) relative to its highest potential rate of output. Even this definition admits different interpretations, since the ' highest potential rate of output ' depends on the range of comparison which is being considered. For the moment, however, we will assume that the highest potential output rate is a known characteristic[4] of the machine. As we saw, transfer presses tend to produce components rather faster than the line of single-blow presses which they often replace (though not nearly as much faster as the makers imply). If they are installed to produce the same output, they will necessarily remain idle for more of the time. The faster they produce, the more time they will spend idle; yet they are doing adequately the job for which they were installed. Should machines therefore be designed to work faster? If they can produce the required output very quickly, then the time they are not working represents ' spare capacity ' in a crude sense—always assuming that extra people can, if necessary, be found to work them. Thus a firm which is expecting an increase in demand might do well to install a fast machine, just so that, as their demand rises, they will have the capacity to satisfy it. Also, as was emphasised by the production engineer at Green's, a faster machine taking up no more room will be producing more from a given space; and compactness may be considered very important. On the other hand, the transfer press (say) may be feeding a line which works rather slower than it does itself; and in such a case some of the components it produces will have to be stored before being put down the line. The components produced by such a press are almost always bulkier than the strip which is fed into it, and will thus take up more space to store. Also, putting half-finished components into an intermediate store (even a small one) in a line and then taking them out again may very well be an expensive operation, requiring either a worker or a specially designed machine. In view of this it may be better to slow down the operation of the press to keep pace with the line rather than incur these ' transferred ' or ' hidden ' costs. Of course, the spare capacity will still be there, although it may be necessary to install a duplicate production line if it is desired to take it up.

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[1] We do not propose to give a general discussion of the many different theories of capital, the diversity of which is partly due to the many different questions and cases which can be brought under this head. We will limit ourselves to discussing the particular questions which have arisen in the course of the above case studies—and which, we have reason to believe, still cause controversy in many parts of industry.

[2] The reader may be familiar with the treatment of such topics in P. W. S. Andrews' *Manufacturing Business* (1949). Chapter III, on the effects of changing outputs on the costs of production, is especially relevant.

[3] See pp. 151–156.

[4] But see the third concept of utilisation given below.

The reverse problem often occurs, namely that of having a machine too slow for the line it serves. In a marmalade factory which we visited, the automatic filling plant could not keep up, in peak periods, with the flow of marmalade from the vats. Hence the filling line was duplicated by having several operators using jugs (and a spoon for a final adjustment). It was not considered worthwhile to install a second filling machine.

Clearly, then, ' under-utilisation ' may not be a crime—especially if a machine is being run slowly to keep pace with a line. What then—apart from the ' idle capital ' argument—is the economic reason for the pressure to increase utilisation, and how far should it be pushed? Let us take a simple case. A piece of equipment is becoming obsolescent at a constant rate, irrespective of its use. (Perhaps the best example would be the tool for a heavy press, for in practice fashion determines its life rather than the number of components which it is used to make). The cost of having the equipment in a particular year is F (for fixed cost). Let n be the number of components made with it in that year, c the direct cost per component, and s the selling price per component. Then the total profit made from the component is

$$P=n(s-c)-F \qquad (1)$$

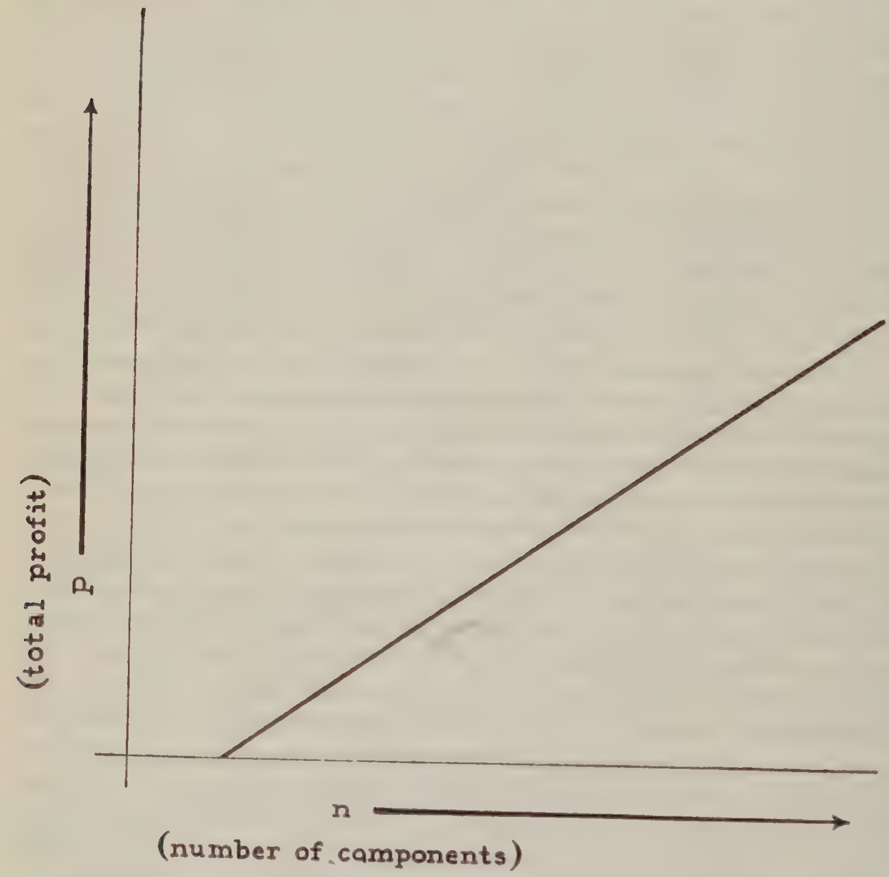
If F, s and c are fixed, the graph of this function is a straight line, as in Diagram IV. The higher n, the higher the profit (P). On the other hand, the cost per component is

$$e=c+F/n \qquad (2)$$

and this relation gives a curve like that in Diagram V. Thus the savings incurred by making an extra component get less and less the more components were being produced in the first place.[1]

Clearly it would be unrealistic to assume, however ' perfectly ' competitive the market might appear, that all savings in cost would be passed on to the consumer—if only because the workpeople are likely to demand and obtain some share. But even apart from this the consumer is by no means

Diagram IV



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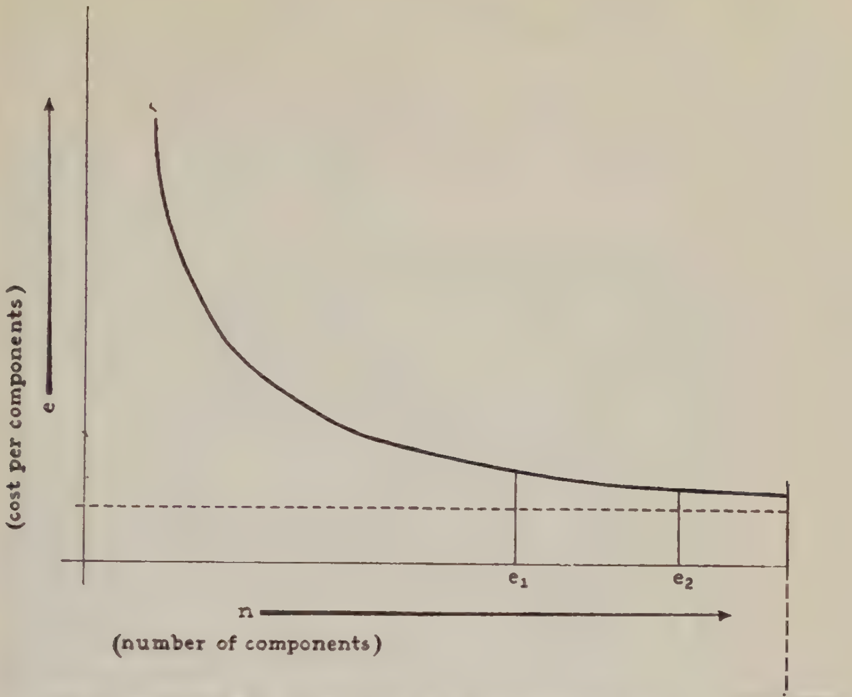
[1] The savings do not, of course, go on diminishing indefinitely: the curve (and our present analysis of its implications) stops when the machine is working at maximum production.

Diagram V



a) The 'possible' limit of production is of course subject not only to 'technical' factors but also to social conventions and regulations—*e.g.* on night-shift working, on the frequency of maintenance, and so on.

sure to benefit; for small savings per unit will be unlikely to be passed on in any case. Since the higher the initial level of production the smaller is the saving to be expected from an additional unit of output, after a certain level of demand has been satisfied (the level depending on F, the fixed cost of the equipment), demand will not be sufficiently sensitive to price—*i.e.*, elastic—for a change in price of the order of e_1—e_2 to be noticed by the purchaser. Thus we may expect that the saving will in fact not be passed on,[1] so that beyond a certain level of output the selling price will be kept constant—and the producer will benefit from any increase in demand that occurs in the way shown in Diagram IV. However, Diagram IV pre-supposes that increases in demand arise spontaneously—*i.e.* that the manufacturer is not spending money on advertising or on other selling devices in order to dispose of the additional units. It follows that there may be profits to be gained from using spare capacity—providing that these are not swallowed up by incurring additional costs in the effort.

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[1] A manufacturer with whom we discussed the point confirmed this view. He said, in effect, that in his line of business no cost reduction smaller than 10 per cent would be noticed by the consumer—and it would therefore not be passed on. A reduction of more than 10 per cent (calculated at existing rates of equipment utilisation) would be passed on; but his competitive position was such that he would then expect an increase in demand, and the consequent rise in utilisation would give him a better profit.

Advertising is only one of the possible additional costs that may be incurred; another cost may be that of an ancillary piece of equipment which is itself not being used very fully. Thus, in one of Black's studies of the utilisation problem, the cost of a 40-ton transfer press was £8,000; and they assumed for it—admittedly by convention rather than by estimate—a life of 20 years. But the tools for processing a particular component cost £2,600 and the component was not likely to be manufactured for more than three years. Thus at this rate the total cost of tools, over the whole life of the press, was likely to be more than double the cost of the press itself. At one time Black's were considering making two components alternately on the press, just to keep it running; but this proposal would have meant that at any given time one set of tools would be lying unutilised in the tool store—which would represent a more important case of under-utilisation than that of the press. (Black's analysis eventually showed this up, in a rather different way.) This kind of situation illustrates the danger of insisting on the fuller utilisation of a large piece of equipment just because it happens to meet the eye and because it is only too obvious when the wheels are not going round—whereas capital locked up in the tool store can be more easily forgotten. By contrast, we were informed[1] of another firm (producing a wide variety of products) where machines were deliberately kept permanently tooled up, ready for special orders for their particular products. In this case, although the machines (which could no doubt have been used with different tools to make different products) were ' under-utilised ', they were kept so because the firm considered that tool change-over costs were high enough to nullify any savings that might have been achieved by using the machines more fully.

This contrast in attitudes towards the utilisation of machines—and each attitude may be justified in certain circumstances—is paralleled by a contrast in firms' attitudes towards the utilisation of men. A machine-minder could be regarded as less than fully utilised, in the sense that he is actively working only a small part of his time; but whether he is truly under-utilised depends on how feasible and cheap it would be to give him other useful jobs[2] to do where his principal job allows it. Machine minding, in fact, may or may not be an expensive form of insurance. This point, and indeed many other equally pertinent points, was brought out in detail by J. M. Clark in his classic work on *The Economics of Overhead Costs* (Chicago, 1923):

> ' . . . We might take a machine as an example. We can develop the latent capacity of a machine by spending labor lavishly to see that it has a continuous supply of material and that it can always get repairs the instant that they are needed and is watched every minute. This would mean that machine tenders would not be taking care of as many machines as they

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[1] By the Production Engineering Research Association (PERA) when we visited them at Melton Mowbray.

[2] Such minor fill-in jobs are aptly referred to by firms as ' knitting '.

> might, and it would mean that the repair force would be quite as large and might spend a great deal of its time waiting for something to go wrong. It would mean that the capacity of the machine tenders and the repair men was being imperfectly utilised in order to utilise more fully the capacity of the machines themselves.
>
> ' On the other hand, the management might try to have every laborer tend as many machines as possible. As a result the capacity of the laborer would be brought out much more fully but the machines might not work as well.'[1]

In fact, the world is full of little-utilised yet ' productive ' things, from foundry patterns to press tools, from car-starters to railway carriages, and from kitchen implements to cranes. The fuller utilisation of such things would result in gains, subject to two reservations. If firstly, fuller utilisation merely means that the thing wears out more quickly, then the gain will be confined to that of a reduction in the average time elapsing between the making of the thing and the achievement of each given amount of production with it,[2] and there will be no saving in the total quantity of labour, etc., which was put into it. Secondly, the hyperbolic curve of Diagram V may, at the rate of current usage, already be sufficiently near its lowest point (either because the original cost was low or because the present usage is high) that there will be no significant advantages in utilising the thing more highly.

(ii) The above analysis would, *mutatis mutandis*, apply to a second and different (but equally useful) concept of utilisation. Instead of taking the actual rate of output per year relative to the potentially ' best ' rate, one takes the total output actually produced before the machine or equipment is in fact scrapped in relation to the total output that could have been produced if it had been run until it finally wore out. The distinction between definitions (i) and (ii) is important in the case of certain kinds of tools—for example, gear shapers—which may be utilised comparatively little during a particular year, but which are normally used until they are completely worn out. In such a case, while on definition (i) utilisation in a particular year might be, say, 30 per cent, on definition (ii) it would be 100 per cent. However, it is often very difficult in practice to determine how many components a machine can produce before it finally wears out; but this concept can still be useful if one restricts oneself to calculating a *relative* utilisation figure for two different machines (or possibly for one machine in two different situations)—*i.e.* to reckoning how many components one machine will produce before it is scrapped compared with the corresponding figure for another machine.

(iii) Some engineers use a third definition of utilisation, when they are interested in problems such as the following.[1] If one considers a milling machine, the tool is in contact with the metal on which it is working only for a fraction of the time during which the component is in the machine. Thus, even though the machine runs continuously, its utilisation is low in the particular sense that the tools are not working on the metal all the time. If another machine were designed to take the same type of tools, but the tools were so arranged as to be in contact with the metal all the time, then clearly this machine must be doing the job faster than the other—*i.e.* components would be coming off it in quicker succession. Thus this concept of utilisation represents an attempt to compare the efficiencies or inefficiencies in the design of machines—though it does this only in a special sense. Of course—as with the other concepts—the value of increasing utilisation has to have offset against it the costs of doing so—in this case, the costs of designing, manufacturing, developing and installing the 'superior' machine. Also, achieving higher utilisation in this sense amounts to making a machine which produces faster; and, as we have said before, there may be no advantage in this if the machine is to be in a production line which cannot keep pace with it. Moreover, if faster production is really wanted, this might also be achieved by merely duplicating the older and slower machines: a possibility which therefore ought to be brought into the comparison.

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[1] *Op. cit.*, p. 75. The insights into the economics of industry which abound in Clark's book were rather neglected by economists, who seemed content, for example, with their smooth and not always realistic production curves. However, the balance has been partially redressed, in this respect at any rate, by more recent models—including those set up for solution by linear programming methods, in which spare capacity plays a crucial role.

[2] But such delays may have a very different importance for different firms, different countries, and different times—depending on the 'shortage of capital ' prevailing.

We may conjecture that it was the kind of view of utilisation just described that inspired, at the turn of the century, the development from the single-spindle to the multi-spindle automatic lathe. Whereas in the former only one out of the four or six tools is in contact at any given time with the metal on which the machine is working, in the latter all the tools are working on the metal nearly all the time. The rate of production of the multi-spindle lathe is thus the faster, but it is not faster than that of a battery of single-spindle lathes; moreover, if the tools are wearing out in direct proportion to the number of components made, there is no saving in tool cost in switching from a battery of single-spindles to a multi-spindle. However, there is a saving in space; and there may possibly also be a saving in machine cost. At any rate, a comparison based on this concept of utilisation is not sufficient in itself to decide a choice between two types of machine: other data and other comparisons must be taken into consideration.

(*c*) FLEXIBILITY

Flexibility in a machine, or the possibility of using it—without incurring a lot of extra expense—in different ways (perhaps even in a way not envisaged when it was originally decided to buy it), is an important characteristic of any new piece of equipment. The purchase of a new machine (or its development inside the firm which proposes to use it) is often justified by reference to some break-even point of output: 'the machine will have paid for itself by the time it has produced so many components.' But if there is any danger of the demand for these components drying up before this time, whether because of competition from other manufacturers or because the product itself is superseded, the question of possible alternative uses is bound to arise. Obviously, it is only if a high and continuous demand is assured, or if the break-even point is very low (*i.e.* if the previous process was relatively very inefficient, or the new machine or equipment very cheap) that the question of flexibility in a new machine can be neglected.

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[1] In this connection, PERA referred us to E. A. Curol, 'Developing Standard Time Data for Grinding Operations' (*Grinding and Finishing*, November, 1956).

The bearing of these considerations is illustrated in various ways in our own case-studies. Thus the manufacturers of transfer presses claimed that they were highly versatile pieces of equipment, in the sense that it was possible to produce a wide variety of components on them. But, since to change from the production of one type of component to another involves heavy tool costs, it is not surprising to find that in this country[1] transfer presses have so far been bought only by those firms which feel assured of steady demand (on the whole, by big firms making things in very large quantities). To judge from the published material of the makers' catalogues, the range of components actually being made on these presses is in fact fairly narrow, and the components themselves small. The firms using such presses are few;[2] the presses are comparatively light,[3] and British machine-tool manufacturers, despite the assurance of protection, have shown little inclination to enter the field.

In Green's, as we have seen,[4] a transfer press had been installed in the production line for which it was turning out partially finished components. Although it was still subject to occasional breakdowns at the time of our visits, it was in fact able to work considerably faster than the rest of the production line and was therefore idle a good deal of the time. This led the local factory management to question the virtue of installing it in the line in order to maintain ' momentum ', and to raise the possibility of its being more fully utilised; could it not be used part-time for the production of a different component altogether? But this was clearly awkward since it had been sited in a specific line—a difficulty which raises the general question whether it is not preferable to install such presses in a separate press shop, especially if there is a possibility of their being required to produce more than one kind of component. Admittedly there will be the problem of feeding the press with different sets of blanks, and of transporting different sets of components away from the press to where they are needed for further processing or packing; but there is a real advantage in being able to centralise press tooling and maintenance. An integrated line, however, aesthetically satisfying (and production engineers are not unsusceptible to such considerations), is an inflexible arrangement.

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[1] One reason suggested to us for transfer presses being used in the U.S.A. much more than here was simply that American markets are bigger.

[2] For instance, the representative of one of the foreign manufacturers of these presses stated that there were only 30 of his firm's presses in Britain—and some firms had several such presses.

[3] We were told that there was only one really heavy (Clearing) transfer press in industrial use in this country.

[4] See pp. 142–143.

Transfer presses are, in effect, integrated sections of line in themselves, and pose some of the problems of inflexibility on a smaller scale. Indeed, except for the consideration of compactness and space-saving, it may well seem preferable to many firms to use lines of single-blow presses linked by transfer machinery, if only because such presses can always be detached from the line singly and used for other purposes if the need should arise. By comparison, transfer presses are inflexible in this sense—*i.e.* if utilisation is an important consideration—unless they are built on the 'unit principle' (which has so far been adopted only for the biggest types):[1] for any stations which are not required in the production of a particular component necessarily lie idle.

In short—the inflexibility lies in the danger of providing excess capacity as distinct from spare capacity. Spare capacity is one aspect of flexibility: thus when Green's installed an automatic phosphating process with a capacity greater than was currently needed, they were proved right by events in that, when the demand grew heavier, they were able to meet it without difficulty. Their experience with the transfer press, however, was less happy. In the first place, while they ordered a press adequate to cope with their current requirements, by the time the press arrived they had decided to use heavier material for the components in question—with the result that the press was somewhat overloaded and therefore liable to breakdown. The results were, firstly that they had to get experts over from Germany to cope with the trouble; secondly that, while they had hoped that the speed of operation of the press would obviate the keeping of stocks of processed components, they were actually forced to keep bigger stocks than before in order to tide over possible breakdowns; and thirdly, their having installed the press in an integrated line made it difficult to switch to an alternative output. All these troubles illustrate various kinds of inflexibility; and in order to overcome them without considerable expense a good deal of 'flexibility' is required of management and technicians.

Brown's procedure in installing their mechanical moulding process was, by contrast, cautious and empirical. They experimented in a small way with a type of machine which was pronounced by its manufacturers to be unsuitable for the purpose required. Their success impelled them to continue, and they ended by allocating their output in such a way that only the heaviest and most difficult jobs were left to the more primitive methods of floor moulding. In effect they achieved flexibility by retaining the old process alongside the new—and possibly also by not installing conveyors to exploit the speed of their mechanical moulding machines more fully, which means that they may still be in possession of spare capacity which can be taken up if the need arises. However, if the spare capacity is not taken up, it is apt—

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[1] And even this device does not get round the need to dig expensive new foundations every time a unit of the press is moved.

after the event—to look like excess capacity; but it may nevertheless be a worth while insurance (if it is not bought too dear) against the uncertainties of fluctuating demand.

There is an analogous dilemma confronting firms when they are proposing to introduce innovations: should they design their processes to take advantage of the flexibility of general-purpose machines, or should they buy or develop special-purpose equipment? On the whole, Black's and Green's were planning for large-scale production, despite the vagaries of fashion and demand to which they were sometimes liable. They were therefore prepared to spend a good deal on equipping themselves with transfer presses—rightly treating these, for all their advertised versatility, as special-purpose equipment. After all, firms usually buy their equipment for specific production programmes, so that versatility may not be a consideration that finally determines their decisions. This is especially true if the firms' engineers are obliged formally to justify proposed expenditures: inevitably, the justification will have to be based on the suitability of the proposed new machine to a specific task. (Brown's, as usual, provide the exception.)

The same considerations apply to the life of the equipment. New machines—even general-purpose machines—are intended primarily to fulfil a production programme covering a finite foreseeable period. If the machines can still be used after the planned production period has ended so much the better; part of today's capital is an accident of the needs of yesterday.

(*d*) Replacement and Innovation

Whether a piece of equipment has a potentially long life or not, is often a haphazard matter. Some machines have necessarily to be reliable, and are therefore built in a substantial and costly way—which often involves a potentially long life, even though this characteristic may not have been intended by the makers or wanted by the buyers. Other machines also have to be built substantially, simply because they are needed for heavy duty. Presses notoriously last for half a century or more. On the other hand tanks to hold chemicals, however solidly they may be made, tend to be corroded in a few years, and it would no doubt be very expensive to prolong their lives. In cases where the equipment is subject to wear and tear, it is sometimes easy to replace the worn parts; but sometimes it is so difficult and costly that the whole thing has to be replaced. Thus, in industry as a whole, the incidence of potential life-spans will be very uneven and sometimes quite unpredictable. However, firms obviously do not exhaust the potential lives of all their equipment before deciding to replace it; and our case studies have suggested some tentative points on this question.

We have already touched on it in connection with the second concept of utilisation discussed above; moreover, the diagrams given in that section are helpful here too. If the machine is expected eventually to be replaced by one of exactly the same kind (*i.e.* if no technical development is taking place), then there is obviously some advantage in going on using it for as long as possible.

First let us assess this advantage from an Olympian standpoint, from which we consider the production of the community over a long span of time without giving any special weight to any particular period (though no mortal person or institution will ever make decisions from such a standpoint). From a welfare point of view, one is interested in the rate at which resources are spent on production over such a time-span; and the savings per year which are obtained specifically by a policy of prolonging the lives of pieces of equipment diminish as these lives lengthen. Thus while the community should be greatly concerned to get certain minimum lives from its machines, after these minima have been achieved it need worry less and less—on a long-term view—about designing policies to make the machines last a little longer. Firms, however, are more inclined to decide things as they go along than according to timeless conventions and policies. They may well be attracted by the prospect of making their machines run just a little longer, especially if it is clearly profitable for them to do so because they are able to keep their prices high even after they have 'recovered' the cost of their machines[1] while their competitors may not yet have reached such a position.[2]

This analysis, resting as it does on the assumption of a technologcally static economy, is incomplete. Not only does technical development take place, but the relative costs of the different factors used in and by the machine will change—perhaps owing to technical development in other industries—so that the machine will have to be adapted or redesigned to meet the new economic situation. Thus C. W. Griffiths, accountant of Joseph Lucas (Industries), Ltd., insists that:

> 'There can only be a limited class of work for which it is worth while to keep plant until it is finally worn out. Except for operations of the lowest engineering standard it generally pays to replace a machine long before it is physically exhausted. The economic life of plant may be determined by the rising costs of maintenance and overhauls, by improvements in the design of new machines, or above all by changes in manufacturing methods. As a result of the progressive development of new materials and new techniques, the economic life of plant in the larger mass-production factories is steadily diminishing.'[3]

On the face of it, certainly, technical development would seem to lead to cutting short the life of machines as the advantages of their successors become manifest. But the operation of this force is sometimes counteracted. If the direction and speed of technical development are fairly clear to a firm

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[1] *I.e.*, they have been selling their output at a high price because they and their competitors have, in effect, under-estimated the life of their machines.

[2] On the other hand, some firms may compare the average cost per year of buying machines (represented in their accounts by 'depreciation') with the costs of running them—the costs, that is, of machine operators or machine minders, maintenance men, tool and machine setters, and the replacing of worn-out tools and machine parts. If they find the depreciation element small in relation to running costs, they may be temped to buy new machines without exploiting the old ones to the utmost.

[3] *The Economics of Plant Renewal and Replacement* (paper written to be presented at a General Meeting of the Institution of Mechanical Engineers in March 1957, and published by the Institution).

(for example, if like Black's they take the lead in designing their own improvements, or if like Green's they keep a special workshop in which to test out new devices), they may prefer not to install a machine incorporating the current improvements but to defer the installation until the next round of improvements—which may already be being discussed—can be incorporated.[1] If however a firm is more or less in the dark about technical development, the familiar game of bluff may develop between the machine manufacturers and their customers—the former taking the line that the current improvement is the 'last word', and that no further advance is in prospect. The customer buys, and soon finds a tempting new model in the market. Firms whose time horizon is comparatively short—*e.g.*, those facing fashion changes in the demand for their products—will probably be more liable to re-equip as soon as new machinery is developed than to play the waiting game. (By no means all firms, of course, are content to wait passively on the makers of their machines to set the pace of innovation; and we will revert to this point shortly.)

From the community's point of view there are penalties both if firms re-equip too often and if they wait too long. If they re-equip too often, resources are being wasted in the machine tool factories—not to mention the resources involved in transporting, installing, and 'de-bugging' the succession of machines; if they wait too long, resources (probably chiefly labour) are being wasted by the firms themselves.[2] But judgments that innovation is undertaken 'too often' or delayed 'too long' may again appear timeless and Olympian, since firms may continually be acting according to the best information available to them at the time they make their decisions. However, firms' decisions are sometimes influenced more strongly by routine and convention (or—as in the case of British Railways for so many years—by lack of capital) than by fresh assessments of the merits of each case; and it is not so Olympian to judge the effects of routines and conventions from a long-run point of view. One of the difficulties that struck us forcibly was that, when firms aspired to make fresh assessments of the machines they proposed to buy, the information on which they actually worked was often very thin. This is understandable enough if the proposed machine is radically new in design; but even if it has been well tried elsewhere, the firm may find great difficulty in getting details of the costs of running it and of how long it will last.[3] Where the machine is similar to one which the firm has already used, one might think that full information would be available; but this is not so by any means. In small firms, the people who make the decisions can, ideally, know all the relevant facts about their machines; but in large firms this close connection is quite impossible. The executives have to rely on the data thrown up by the costing system,[1] and the only alternative is to order special investigations.

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[1] In our case studies, we did not happen to notice any case of such a waiting game being played.

[2] Moreover, this type of policy will not attract good technicians to a firm or an industry.

[3] The production engineer at Green's told us that he had found little difficulty in getting information on costs for transfer presses, etc.—though not from very close competitors. However, both he and his well-staffed private workshop in which new machines are tried out represent a use of resources designed to bring information into the firm. Nor were the machines which were being tested always untried elsewhere.

So far we have been discussing the case where the machine-tool manufacturers make the pace in the development of machine design. This is by no means always so. Black's had several development sections devoted entirely to making tools for their own factories, and are building up a considerable reputation in this field. Other examples can be picked up in abundance from the Press: Lyons' developed LEO for their own operation; Austin's developed and built their own automatic line; Renault's did the same, and have licensed the manufacture of some of the machine tools they have developed; Mullard's ran an ingenious advertising campaign around the slogan ' the machine is part of the products ', with illustrations of the highly automatic equipment which they had developed and built to use in their plants.[2]

This practice must have interesting economic consequences, although these have not yet been explored. It amounts in effect to a vertical integration of a rather different kind from the one usually taken. Economists usually think—and this is reflected in firms' accounting practices in such concepts as ' direct materials ' and ' conversion costs '—of the economic process as one of transforming raw materials into finished products with the help of labour and machines. In this context, the process of vertical integration means the taking over by a firm of more and more of the processing—and eventually the production—of its ' direct ' raw materials and the components it uses.[3] But the tendency we have described is one of expanding along another limb of the productive process: *i.e.* of making the machines which, as we have pointed out, are intermediate inputs of the process just as surely as the material with which the machines deal.[4]

There has been a good deal of discussion of what is possibly a tendency to move away from vertical integration in the ordinary sense—*i.e.* a tendency for firms to slough off the control of their raw material supplies, and to farm out the manufacture of components and even sub-assemblies. In this way industry claims to be taking advantage of economies of scale in the manufacture of components, etc., since component makers can supply more than one firm. Perhaps the economies of scale in machine-tool manufacture are smaller, so that firms may not be sacrificing too much in expanding along this particular limb while contracting along the other.

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[1] The importance of cost and works accounting is certainly recognised fairly widely in industry; but the information required to analyse the performance and cost to firms of particular pieces of equipment is usually far more detailed than even the most elaborate costing system will produce. Costing systems often aim to do no more than enable firms to fix a ' reasonable ' price on its products, and for this purpose the familiar technique of counting up the various inputs and adding a proportion of ' general overheads ' may get by. But even the more sophisticated systems of standard costing, where the purpose usually is to improve performance in relation to various ' objective ' standards and show up points of inefficiency, rests on a whole series of assumptions which may not be appropriate if one is interested in a particular machine or process.

[2] This tendency of firms to make their own equipment (and how widespread it has become we cannot tell) has been attributed by some of those to whom we have talked to the conservatism of British machine-tool manufacturers in sticking to the production of standard types of machine. On the other hand the President of the Machine Tool Trades Association is quoted as having said that only 10 per cent of the demand for machine tools in this and other countries is for ' automation equipment ', and that the demand for standard machine tools would even be increased by the growth of automation—though it is difficult to see how the implied demarcation line could be drawn.

[3] This simplified view is inappropriate in many cases. In a foundry, for instance, most of the work goes into processing the *indirect* material to make the moulds.

[4] An analogous extension, along yet another limb, is the increasing effort of firms to train their own technicians, engineers, and operatives.

But some economies of scale may nevertheless be sacrificed. On the face of it, for firms to make their own machines may hinder the flow of information from one firm to another about new developments in manufacture. A specialist firm in the machine-tool trade will obviously try hard to bring the advantages of its new machines to the notice of all potential users. But if a firm designs and makes its own machine, unless it decides to license out its manufacture, there are fewer ready-made channels of information through which other firms may learn of it and assess it; and in any case these other firms would have to build it from scratch, which certainly represents a sacrifice of an economy of scale. In general, the flow of information in industry, dammed by the exigencies of trade secrecy yet carried forward by the urge to exhibit one's technical achievements to those who are at the same time colleagues and rivals, is one of the least charted but most important features of technical progress.

(*e*) The Importance of Depreciation Calculations

We have seen that not all firms consider it necessary to make detailed cost calculations before they install new equipment. Some may decide, as Green's did in some cases, that there are obvious bottlenecks in their productive process where it is clear that an investment in new equipment will pay off (' naturals '). Others, like Brown's, may have a policy, or face a situation in which costs are not the dominant factor. However, even in these cases, some costing is usually done, and in the case of Black's a careful set of calculations was performed to support each decision. Since these were the only calculations of this type which we saw, the remarks that follow will be much influenced by them. The subject is too wide and diverse for a thorough treatment here: even with the most detailed costing there can be wide variations in the calculations and conventions which may be used;[1] moreover, the calculations which firms carry out, and their ideas on equipment and replacement policy, may influence each other strongly.

The situation which concerns us is one in which two machines or pieces of equipment which do a similar job are being compared. Such a comparison may be of a machine which has been doing the job up to now with a prospective successor; but the simplest case is the comparison of two fresh pieces of equipment in order to decide which of them should be bought. These pieces of equipment will almost certainly differ in many of their characteristics

[1] See p. 200, n. 2.

including perhaps their price. One may last almost indefinitely with proper maintenance, whilst the other may wear out—either with the passing of time (like the tanks to hold chemicals which we mentioned above) or after a certain amount of use (like cutting tools). They may need very different amounts of labour to operate them. They may differ in flexibility, so that if the demand for the product fails, one machine may be useless, while the other may easily be transferred to other uses or sold. They may differ in ease of installation or dismantling, and this too will affect their flexibility. These and other differences must be taken into account in bringing on to a common scale the costs of buying and installing the machines and those of running them.

The necessity of reducing different kinds of costs to a common scale presents cost accountants—and those who want to make use of their results—with a hierarchy of problems. Even the measurement of ' direct ' costs is not easy, and accountants generally use ' standard ' rather than ' historical ' or actual costs. Indirect costs—management time, wage office time, factory lighting, etc.—have to be brought on to the scale, but the problems of allocating such costs are often ' solved ' by resorting to arbitrary conventions of a type which may be unsuitable for the comparison in hand.[1] But these questions, important as they are, will not be our concern here. If we are not to embark upon a treatise on costing, we must select one central problem. We want to consider how the cost of a machine—a lump sum spent at a particular time—is to be brought on to the same scale as the running costs which will be incurred throughout its life.

The method used by Black's is the straight-line depreciation one common in industry. First, a life-span is postulated for the machine which is to be bought. This life may be determined by considerations of likely fashion, or obsolescence (of the product as well as of the machine), or sheer endurance—always subject to the time-horizon which the firm sets itself.[2] For example, the more flexible the machine, the longer—other things being equal—one would expect its estimated life-span to be. In practice, however, life-spans are strongly influenced by convention: thus, as we have seen, presses (both single-blow and transfer) are credited with fifteen or twenty years. The cost of the machine is divided by this assumed life to give an annual depreciation charge: if a transfer press costing £15,000 is thought likely to be used for 20 years, this charge will be £750.

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[1] Some accountants have gone so far as to say that ' the analysis of cost according to directness has never been intended to reflect the variability of cost with output. It is a measurement of the ease of apportioning expense to cost centres and cost units—direct costs being apportioned on an actual basis ' (*sic*) ' and indirect costs to an arbitrary basis '. (*Accountancy*, Journal of the Institute of Chartered Accountants, August 1958, p. 294.)

[2] Many firms use a different type of approach to the costing of their equipment. Instead of imputing a life-span to a machine or a process, they ask ' How soon will it have paid for itself ? ' The difference can be more apparent than real, since machines with a long expectation of life may be granted a longer time in which to pay for themselves. For an admirable discussion of the implications of this type of calculation, see J. A. Scott (Chief Financial Executive of Hayeshaw, Ltd., Manchester), *The Economics of Plant Replacement*, paper published in the Proceedings of the Eighth Summer School of the Institute of Cost and Works Accountants, 1957.

If the capital cost of £15,000 is spent now, and £750 is set aside every year, then (if interest is neglected and prices do not alter) the firm will, in twenty years' time, have just enough money to buy a new machine of the same type or cost. Since the £750 must be set aside every year, it is considered at this stage as a cost of having a machine—in, for example, calculating the return on capital, or the price which can be charged for the product. It is the cost of maintaining capital intact. It may seem strange that no interest charge is included in the calculation, and we will return to this point below.

Should installation costs be included in the sum to be depreciated in this way? When concrete foundations are built, the firm spends money, which it may want to ' recover ' by a depreciation charge. It will probably need a similar sum again, either when the machine is replaced, or when it is moved to a new site—perhaps because the line it is in is to be reorganised, or because it is to be used in another line. Thus, on this reasoning, installation charges should often be depreciated on a shorter life than the machine itself. And the ' life ' of an installation in a line should be shorter than the ' life ' of an installation in such a place as a press shop.[1] Thus depreciation can be reckoned as a future running cost when one is comparing two new machines before they are bought.

This is not to say that depreciation is always the appropriate figure to reflect the cost of using capital resources—for instance, if work is to be re-allocated on machines already in use, and possibly also if an existing machine is to be replaced by a new one. In the first case it may be desirable to employ a system of ' shadow rents ', *i.e.* to attribute different running costs to different machines. To achieve a sensible re-allocation of work, these ' shadow rents ' should be inversely related to the spare capacity of each machine: that is, they should represent the pressure of use on each piece of equipnent. Clearly such ' shadow rents ' may not be at all similar to the existing depreciation charges on the two machines. Yet, because the depreciation is already associated with the machines as a ' charge ', it may be made to do service, however inappropriately, as a ' shadow rent' .[2]

Now we may consider what kind of calculations are done when it has to be decided whether a new piece of equipment should take the place of an old. Such a question may arise either before or after the assumed ' life ' of the old equipment has expired. One way might be to assess the life of the old machine afresh, and compare the costs of running it again with the costs of buying a new machine, offset by the scrap or resale price (if any) that one could get for the old one. Thus on this method the depreciation cost for running the old machine would be the scrap value for the old machine (since one has forgone obtaining this price by continuing to use the machine) divided by its expected life—the time one plans to go on using it. This method was apparently used by Black's, but with one modification. Instead of the scrap value they used the ' unrecovered depreciation ' for the machine —that is, the cost price minus the sum of the annual depreciation so far imputed to the machine. But the latter may have no relation to the scrap value at all. Indeed, if the machine is difficult to move, or inflexible, or expensive to run, its resale value may be nil, whatever the ' unrecoverable ' depreciation. Thus, in the case of special-purpose equipment, such a practice gives a bias *towards* installing the new machine, since it makes the cost of continuing with the old one appear higher than it would be if assessed at the true scrap value. Of course this bias would be lost after all the depreciation on the old machine had been recovered, that is, after it had finished its estimated life.[1]

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[1] However, some installations (such as concrete pits, etc.) may occasionally be more flexible than the special-purpose machinery set up upon them—in which case they may have a longer useful life.

[2] Shadow rents are analogous to the rents of premises in a free market. One of the characteristics of these rents is to reflect pressure on resources. Economists have suggested that the same mechanism could be simulated within a single organisation in order to achieve a sensible use of resources. (Rents also, of course, involve a transfer of income; but where, as in a single plant, all resources come under the same control, this aspect is irrelevant.)

In practice, as we have said, the life-span of a new machine is difficult to estimate and is decided largely by convention.[2] But the figure decided on, and therefore the magnitude of the annual depreciation charge, can make a very big difference to the estimated costs and therefore to the decision to innovate. For example, the life of the new IWK transfer press in Table I above was assumed to be 20 years; but if it had been—not implausibly—put at 10 years, the depreciation charge would have been doubled and the saving on the new process would virtually have been halved (Table X).

The shorter the life assumed for the new equipment the more expensive it seems. Also, the ' unrecovered ' depreciation on the old equipment (which Black's used in some of their estimates as if they were identifying it with scrap value) reduces quicker with age the shorter the life that was originally assumed. This situation leads to an interesting paradox. Suppose we are comparing two firms, Short's and Long's. Both follow the above accounting practices, but Short's impute short lives to their machines while Long's impute long lives to theirs. The cost of a new process will always appear higher to Short's than it does to Long's. Thus, if they make their decisions on the basis of calculations of the type described, Short's will tend to hesitate longer before going over to the new equipment than Long's do. It follows that the firm that tends to estimate its equipment as having the shorter life in fact will tend to run it longer. The same effect will occur even if the firms find out the

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[1] In at least one of their calculations which we saw, Black's entered only a single year's unrecovered depreciation on old equipment to offset the cost of new plant. The rest of the unrecovered depreciation was treated as a bygone and ignored in this context: ' any other procedure would handicap the works engineer too much '. This seems to run counter to the firm's general bias towards re-equipment.

[2] It is sometimes said that this convention, in turn, is influenced by Inland Revenue conventions about depreciation. However, Inland Revenue conventions are necessarily based on some sort of 'average experience'; and, while firms should take tax allowances into consideration in their cost calculations, they should (and do) also base such calculations on their own production policies, plans, and assessments of the future,

TABLE X

Effect of Differences in Assumed Life-Span on Savings Calculations[1]

Cost of new IWK 9-station press			£20,358
Unrecovered depreciation on old single-blow presses			£3,700
Costs per year (£)	*Old method*	*New method*	*Saving (+ or −)*
All costs other than depreciation	19,956	17,067	+2,889
Depreciation:			
(*a*) for life of 10 years	370	2,036	*−1,666*
(*b*) for life of 20 years	185	1,018	*−833*
(*c*) for life of 30 years	123	679	*−556*
Total saving per year:			
(*a*) for life of 10 years			+1,223 (7%)[2]
(*b*) for life of 20 years			+2,056 (12%)
(*c*) for life of 30 years			+2,333 (14%)

[1] This table is based on Table I above; but it is intended only to illustrate the effects of assuming different life-spans for the presses, and other difficulties previously discussed are ignored. Note that in this case (Table I) the firm took the *future* depreciation 'life' of the old machines to be identical with the *total* depreciation 'life' of the new machine: they spread the unrecovered depreciation over 20 years. We have followed this practice in the above table. Strictly, of course, the old equipment, if it were to be retained, might well have to be replaced before this. The comparison should really be between (i) buying new equipment now and (ii) running the old equipment for a given number of years and then replacing it either with fresh equipment of the same type or else with equipment of a new type.

[2] *I.e.*, 7 per cent of the capital cost (the cost of the new IWK press minus the unrecovered depreciation—scrap value?—on the old single-blow presses).

real scrap value of their equipment for their calculations. The paradox arises because the firms are supposed, as they usually do in real life, to reassess their decisions as the life of the equipment progresses. One of the firms at least is systematically misforecasting[1] the decisions that it will itself make (or the decisions that will perhaps be forced upon it): doubts about one's own behaviour in the future are among the uncertainties one has to face in making decisions now. At any rate it cannot be assumed that the life which a firm imputes to a piece of equipment is any measure of the time over which it will use it (let alone how intensively it uses it).

But even supposing that firms' cost calculations had not this element of arbitrariness, we may still ask what would be the minimum annual saving on current expenditure which the firms would expect before deciding to invest in new equipment? Of the firms we investigated, only Black's put the question to themselves in this sort of way; and their answers—in the cases we saw—ranged from 14 per cent of the cost of the new equipment down to zero.[2] But those rates cannot be taken as representing the return which the company was actually expecting to obtain as a result of installing the new equipment: for example, they could expect to recover an allowance on purchases of equipment from the Inland Revenue, and this does not figure in the calculations. Moreover, the innovation with the lowest expected return promised Black's other advantages which were not expressed in the cost calculations—greater flexibility, for instance. In fact, it was not at all clear what minimum rate of return on capital Black's would have countenanced —when they considered it appropriate to think in these terms.

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[1] The misforecast may be an accident, or (in the case of Short's) the result of deliberate caution. In the ordinary way—*i.e.* when replacing fairly standard equipment—firms will, in the course of time, learn from experience and readjust their policies accordingly; but in the case of innovation it is much more difficult to learn, as each situation may appear 'unprecedented'.

[2] About a different group of companies, Sir Miles Thomas wrote (*Sunday Times*, June 23rd, 1957): 'When I was managing director of a group of motor-car factories I was always ready to spend £1,000 of capital to save a penny on an individual operation' (presumably not a penny per component, for then the returns might have been immense).

One might perhaps have expected that this minimum rate of return would be associated with the ' rate of interest ', and that the latter would have been taken into account either (*a*) if the firm had had to borrow money from outside to finance its purchases of new machinery or (*b*) because, if they had the money, in buying equipment they would have been forgoing the interest they could have made by investing it elsewhere. But these two cases—borrowing money from outside, and forgoing interest by spending money on equipment—are far from symmetrical. There are several rates at which the company could borrow from outside (by issuing ordinary or equity shares, or by borrowing from a bank, for example), and possibly other rates at which it would be willing to lend. The bearing of these considerations on a firm's capital expenditure policy was strikingly expressed by the Chairman-elect of ICI:[1]

> ' Given the best long-period forecasts which may be available for a particular new product, the question at once arises: what forecast return is needed before capital expenditure on plant for the new product will be undertaken? The answer is not simple; it is not uniform for all cases. If we are considering a business which is being financed by ordinary share capital, the return must be at least high enough to pay a rate of dividend which the shareholders expect or could get from investing in a similar business. Otherwise the money will not be forthcoming either from existing shareholders or from the general public through an issue on the stock and share markets.
>
> ' In this country, to the gross dividend paid must be added the equivalent profits tax. The average yield on ordinary shares is about 7 per cent today, which with profits tax amounts to 11 per cent. After deducting income tax the shareholder receives about 4 per cent. Thus 11 per cent must be earned on the capital to pay a 4 per cent dividend to the shareholders. Above the profit needed to pay dividends and profits tax, a margin is required to cover the cost of replacing plant and machinery during the present rather inflationary conditions. A further margin is needed to allow for the period of construction when no profits will be earned. This period may be anything from six months to six years or more if heavy constructional work or deep mining is involved. A project which yields less than about twelve-and-a-half per cent profit on the

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[1] S. P. Chambers, ' Investment and Britain's Industrial Future ' (*Listener*, January 24th, 1957).

capital employed would, for these reasons, generally be regarded as wholly unattractive and barely able to pay a reasonable dividend without any margin for reserves.

'If it is safe to rely upon fixed interest loans the interest cost will be substantially below the cost in dividends and profits tax of equity capital, but this form of finance is suitable only for products for which the demand and the prices are likely to be steady over a period of years.'

It is of course very possible that such considerations were reserved for discussion at Black's board meetings, when the various applications for capital expenditure drawn up by the firm's engineers and accountants came before them. But it is not only that there may be no single outside rate of interest which a firm will recognise as representing the cost to itself of borrowing capital: as many people have pointed out, 'no matter what the opportunities, some companies are firmly unwilling to borrow'[1]—sometimes, because of the risk of increased outside influence. 'Major schemes [of re-equipment] may entail raising additional capital. Many schemes show such substantial and rapid returns that even if liquid funds are not available, borrowing will be well warranted. There is, however, frequently a strong reluctance to borrow or even to raise additional capital.'[2]

Again, the idea that a firm will, by spending money on new equipment, be forgoing the interest which it might have got from investing its funds elsewhere assumes—not always correctly—that the firm is prepared to admit the latter as a possibility. But a firm will often prefer to put its money into its own projects, and to limit its choice to re-equipping or branching out into some field where its particular skills seem applicable. Many firms are more interested in earning enough to keep themselves by plying their own trade than—to use a phrase now very much in the air[3]—in becoming investment trusts.

Where firms are constantly re-equipping in this way, the depreciation fund may have scarcely more than a notional existence. The 'investments' made from it consist, partly, of just those projects of re-equipment which are being assessed at any particular time on the basis of the 'estimates of savings' that are being put up to the board. In such cases it is the percentage savings on capital as shown on these forms which really represent the rates of interest which the firm hopes to get on its 'investments'. If capital resources are scarce, the cut-off level may be very high; if they are plentiful, even low-paying projects may be sanctioned—as we found in some of the cases we examined. A lower limit would not then be set by the (unacknowledged) opportunities of obtaining a slightly better rate of interest outside.

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[1] Joel Dean, *Capital Budgeting* (New York, 1951), p. 53—discussed in Brockie and Grey, 'The Marginal Efficiency of Capital', *Economic Journal*, December, 1956.

[2] J. A. Scott, *op. cit.*

[3] See, for example, Brockie and Grey, *op. cit.*, p. 667. However, not all organisations think in this way. The Gaitskell Commission, for instance, found it necessary to admonish the Co-operative Movement for worrying more about its balance-sheets than its equipment: 'the Co-operative Movement is supposed to be a dynamic trading organisation, not a giant investment trust' (*Co-operative Independent Commission Report*, 1958, p. 45).

Moreover, they may in any case not rank their proposed projects in the order given by the percentage returns on capital. In the first place there may be a reluctance, for reasons given above, to spend large sums however promising the return, although smaller sums offering smaller returns may be spent quite freely. Secondly, an investment which is reckoned to produce 10 per cent a year over 10 years may be preferred to one offering 15 per cent over 5. In general, however, one would expect that the uncertainties of the future would tend to predispose firms to the prospect of quick returns. Economists are wont to suggest that this preference ought to be formalised by firms in a rate of time-discount for the future—*i.e.*, that they ought to knock off a given percentage for every year interposed between an investment and a saving resulting from it. But it seems to be agreed that most firms are less rigorous than this.[1]

A reluctance by firms to lend or to borrow outside (especially to or from other firms, directly or indirectly) may lead to shortages of capital in some—and hence to a brake on innovation for those who suffer the shortage. A firm may tie up its capital in some early type of equipment, and then not have enough if the rate of technical development proceeds faster than was expected—thus not being able to rectify decisions which appear wrong in the light of later events.[2] Whether it is right to re-equip must always depend on a balance between the advantages of using the existing equipment long enough (*i.e.* of not spending too much on constant re-equipment) and those of making full use of savings in operating cost offered by new equipment not too long after it is developed. 'Waiting for the next development but one,' may be a sensible policy unless by waiting the firm actually impedes the rate of technical development (which it may do if it normally develops its own improvements). If the firm does not effectively determine the rate of technical development in this way, it should regard the life over which it expects to recover the development charges associated with the present improvement as a long one; for the savings due to this improvement can be considered as continuing to be made when the next one is put in—since the next one depends on the present one. There could clearly be very different imputed lives for the various elements of which the cost of a piece of equipment is built up—machine construction, installation, tooling and (if this has been undertaken by the firm) development. Of these, development would usually rate the longest 'life'; though all 'lives' may be curtailed and equalised by the time-horizon which the firm sets itself.

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[1] Brockie and Grey, *op. cit.*

[2] For instance, aircraft operators have been convinced that passengers will insist on jet travel before existing turbo-jet and piston-engined aircraft have been fully written off; one of them, the chairman of Silver City Airways, Ltd., wrote recently that 'the possible reduced operating costs of a new type of aircraft can only show a hope of reduced fares' (or, presumably, savings to the company) 'if it is purchased *after* all depreciation has been written off the type which it replaces. Until that time the replacement is premature.' (*The Times*, August 7th, 1958). But the earlier decisions may, in the light of later events and innovations, prove to have been wrong even though it was right in the light of the knowledge on which it was based. In that case it would be wrong to refuse to innovate now if the expected savings warrant it.

In fact, the line between capital and current expenditure sometimes becomes indeterminate. A firm may, for example, keep an installation crew continuously employed; and it may be that installation costs will then be counted as an overhead and not as a separate capital cost each time a new machine is installed. A similar situation may arise if the firm keeps a development or fundamental research section, as is increasingly common. The development crew is likely to be regarded as an indivisible unit, and cannot be dismissed and re-employed at will. Its work is thus likely to be treated as current expenditure, and will not be specifically costed in respect of each machine it develops. Such a method ensures that the development cost of particular machines and processes is not subject to the caution which close time-horizons and quick writing-off entail. Such 'built-in' machine development is likely to keep a firm innovating faster.

CONCLUSION

Since the field of innovation in industry is still being intensively explored and is far from fully charted, we have thought it best to lean heavily on a few detailed case studies. While no small selection of cases could claim to be representative or wholly typical, even for the experience of the firms in question (indeed, for the larger firms the projects discussed were comparatively small items which could, in themselves, have been taken in the stride of the firms' capital budgeting), yet the cases do illustrate a number of important issues which are constantly confronting industry—and those concerned with its problems—in one guise or another.

The subjects with which we have been dealing are economic problems of mechanisation, or rather of indirect production at any stage of complexity. Often in this field, technical advance consists of finding the longer detour that proves the quicker way. Such advances can be rapid in some sectors, but have always been very uneven; they have therefore given rise only to comparatively slow increases in the productivity of the community as a whole. We have found no reason to think that the present phase of mechanisation will have the much sharper effect sometimes forecast for it: such forecasts usually consist of unjustified extrapolations to the whole from what is happening in a small part. On the contrary, to achieve even a fairly modest overall increase in productivity, the new machines will have to be designed, bought, and used not only with engineering skill but with economic understanding. As production becomes more indirect, the achievement of higher productivity rests more and more with management; and as such indirect methods become more diffused, so the understanding of such problems as those of flexibility, capacity, utilisation and replacement must be deepened and become more diffused also.

We can of course expect a steady encroachment of mechanised production into further fields—always granting that the problems of balancing demand with increasing production are solved. But there will necessarily be a frontier. It is not enough to say that this frontier will be set by the advances of technology; for whether these advances are consolidated (or sometimes indeed whether they are made at all) will depend on the attitudes of those who control the community's productive resources—firms and public corporations. From the producer's point of view, advances in technology can proceed in many directions: machines may be made simpler or more elaborate, more flexible or more specialised, shorter-lived or longer lasting. An advance may consist in making them cheaper, and perhaps also faster-running. Some pieces of equipment require few inputs (*e.g.* of labour or of power) and prove virtually everlasting: greater cheapness and simplicity of construction are in themselves no reason to replace, say, a bridge. Developments of this kind, however, are rare and almost accidental: at present, nobody is likely to aim specifically at designing machines to last for very many years, if only because few firms ' time-horizons are long enough for them to think it worth while. Moreover, if a machine is actually to be used for a long time, it must be flexible enough to keep pace with fashion or other changes in demand. If demand is changing quickly enough, firms may think it worth while spending money on achieving greater flexibility.; but if it is changing slowly such flexibility will, like potential long life, be a matter of accident rather than of design.

Thus the direction of technical advance must depend partly on the time-horizons of firms, which are usually short although they are sometimes extended by the existence of institutional devices such as research departments, whose projects are less subject to the pressure for quick returns. But it will also depend on the ability, somewhere in the firm's hierarchy, to combine economic insight with engineering understanding; at the moment there is far too little awareness of the need for systematic training in the merging of these qualities.

Beyond the frontier, we can be sure that the older occupations—from hand craftsman to truck driver—will be required. Even in a modern foundry the floor moulder may still ply his trade.

THE

AMERICAN ECONOMIC REVIEW

Volume XLIX SEPTEMBER 1959 No. 4

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